

California AHMCT Program  
University of California at Davis  
California Department of Transportation

**DEVELOPMENT OF TETHERED MOBILE  
ROUTING ROBOT (TMRR)\***

Daehie Hong  
James M. Stiles  
Keith J. Mueller  
Steven A. Velinsky

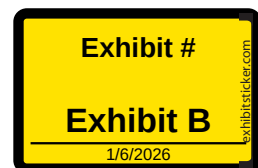
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## ABSTRACT

This report describes the development of a new wheeled mobile robot aimed at automating the crack preparation and sealing process. This robot is a differentially steered wheeled mobile robot with centrally located router and articulated sealant head. Additionally, a laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle is thus necessary, and it is accurately measured through a cable extension transducer based system. This mobile robot is referred to as the Tethered Mobile Routing Robot (TMRR). This report includes the descriptions of this unique mobile robot system and also operational instructions.

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## EXECUTIVE SUMMARY

A large number of highway maintenance activities involve the sealing of cracks and joints, the purpose of which is to prevent the intrusion of water and incompressible. When properly performed, this operation can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitation. The operation is time consuming, tedious, and dangerous to the personnel involved, and accordingly, it is probably the worker's least favorite job.

Automation of this task would be extremely valuable, and thus a unique Automated Crack Sealing Machine (ACSM) was developed by the University of California, Davis through the Strategic Highway Research Program's H-107A project; see Velinsky, 1993. From this research, we concluded the following regarding the robot positioning system; it is desirable to operate on a full lane width  $\approx 4$  m (13 ft) and to have the ability to adequately prepare the pavement which included the use of a pavement router to enlarge the existing crack to promote better sealant adhesion and penetration. However, the router's weight and the forces that occur during the operation exceed the capacity of conventional manipulator type robots. Also, commercially available manipulator robots are costly, have relatively small workspaces compared to that necessary, and the mechanical advantage of the robot is dependent upon its joint positions.

Accordingly, unique concepts have been developed to overcome the inherent disadvantages of the use of conventional robots for highway maintenance operations (Velinsky et. al, 1994). This unique mobile robot was termed the Tethered Mobile Robot (TMR). In this project, the TMR concept is applied to develop the Tethered Mobile Routing Robot (TMRR) targeting a specific application, the crack sealing operation. This document reports on the development of the TMRR at the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California at Davis. The TMRR is a differentially steered wheeled mobile robot with centrally located router and articulated sealant head. A laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle utilizes a cable extension transducer based system.

This document reviews some of the important aspects of the TMRR system development. The mechanical configuration is first presented. Next, the control system is discussed in detail, including hardware and software. The sensing systems including the robot localization system and crack sensing system are then reviewed in the next chapters. The operational instructions are included in detail in Chapter 6.

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#### DISCLAIMER/DISCLOSURE

"The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology Program (AHMCT), within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Research of the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities."

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## CHAPTER 1

### INTRODUCTION

A large number of highway maintenance activities involve the sealing of cracks and joints, the purpose of which is to prevent the intrusion of water and incompressible. When properly performed, this operation can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitation. The operation is time consuming, tedious, and dangerous to the personnel involved, and accordingly, it is probably the worker's least favorite job.

Automation of this task would be extremely valuable, and thus a unique Automated Crack Sealing Machine (ACSM) was developed by the University of California, Davis through the Strategic Highway Research Program's H-107A project; see Velinsky, 1993. In this concept, a conventional SCARA (Selectively Compliant Assembly Robot Arm) manipulator was inverted and mounted on a linear slide to provide a redundant degree of freedom allowing the manipulator to avoid singular positions in its motion and move through any prescribed path in its dexterous workspace. The SCARA manipulator was used to guide a secondary arm over the pavement along specific paths (following cracks). Such an approach provided accurate and consistent relative positioning between the maintenance device and the pavement, and additionally relieved the manipulator of the burden of carrying the weight of the sealant head. The tool's location was determined through the robot's joint positioning. Problems with this configuration include: the fact that the mechanical advantage of the robot is dependent upon its joint positions, the manipulator system is costly, and commercially available robots have relatively small workspaces compared to that necessary; it is desirable to operate on a full lane width  $\approx 4$  m (13 ft). Furthermore, this system did not provide for the ability to adequately prepare the pavement which included the use of a pavement router to enlarge the existing crack to promote better sealant adhesion and penetration. Specifically, the router's weight and the forces that occur during the operation exceed the relatively low load carrying capacity of the robot.

This report presents a new Wheeled Mobile Robot (WMR) aimed at automating the crack preparation and sealing process. This robot is differentially steered with centrally located router and articulated sealant head. The motors provide a large tractive force and the router is located on the center of the wheel base in order for better tracking control performance. The design provides a very small turning radius. Additionally, a laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is mounted to a linear slide for an extended field of view. The robot position relative to the support vehicle is accurately measured through Cable Extension Transducers (CETs), and all power and materials are supplied through the use of a boom/tether. This robot is termed the Tethered Mobile Routing Robot (TMRR).

This document concisely reviews some of the important aspects of the TMRR and includes its detailed operational instructions. The interested reader is referred to Boyden and Velinsky (1993), Hong (1994), Koçekali and Velinsky (1994), Winters and Velinsky (1992), Zang and Velinsky (1994b), Matsumoto (1996), and Chung (1996) which are detailed interim reports and theses of this and related projects, and provide significant detail on all of the areas covered.

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## CHAPTER 2

### MECHANICAL CONFIGURATION

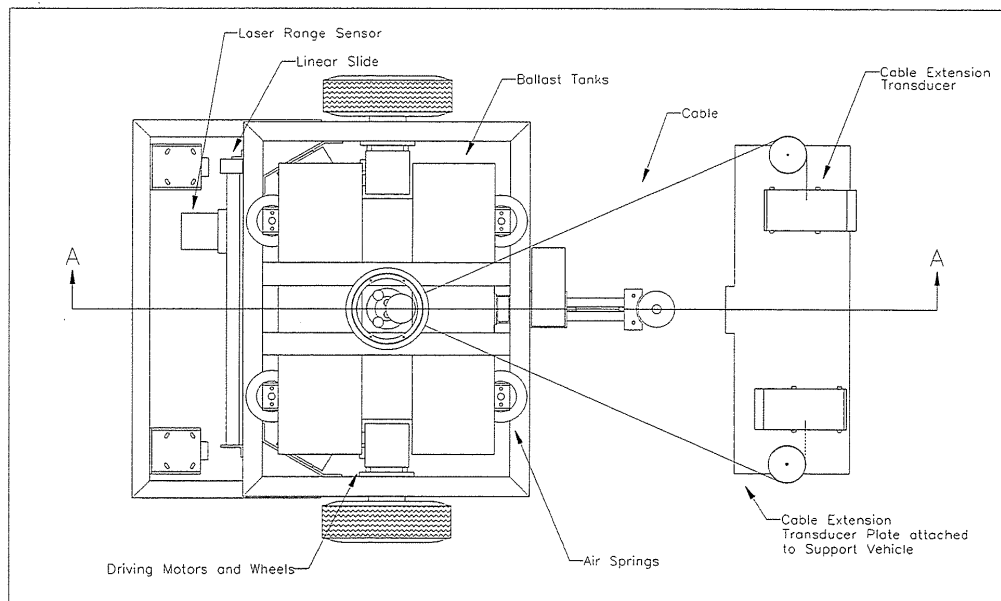
Figure 2-1 is a schematic of the TMRR. Mobility is the key feature in its design. Cracks on roadway surfaces can be very irregular and attempting to follow one through 360° is paramount in a successful sensing/routing/sealing operation. Computing the relative position of the TMRR to the support vehicle is also an added complexity. Our solution for this problem of position estimation is triangulation by two CETs mounted to large diameter radial bearings on the TMRR. Power and material lines drop through the center of the bearings and are either mounted to rotary unions or simply twist with robot orientation. Since the cables' point of attachment is along the center of the drive wheel base, the TMRR can conceivably perform a 360° rotation "in place".

The laser range sensor mounted in front of the router unit finds cracks via triangulation and stores three dimensional surface profiles. The limited view of a stationary laser sensor would limit the TMRR's practical turning radius. To overcome this, the sensor is mounted to a linear slide thereby increasing the possible field of view. Feedback control is provided and the position of the TMRR can be updated in real time using the offset position corrections of the laser sensor.

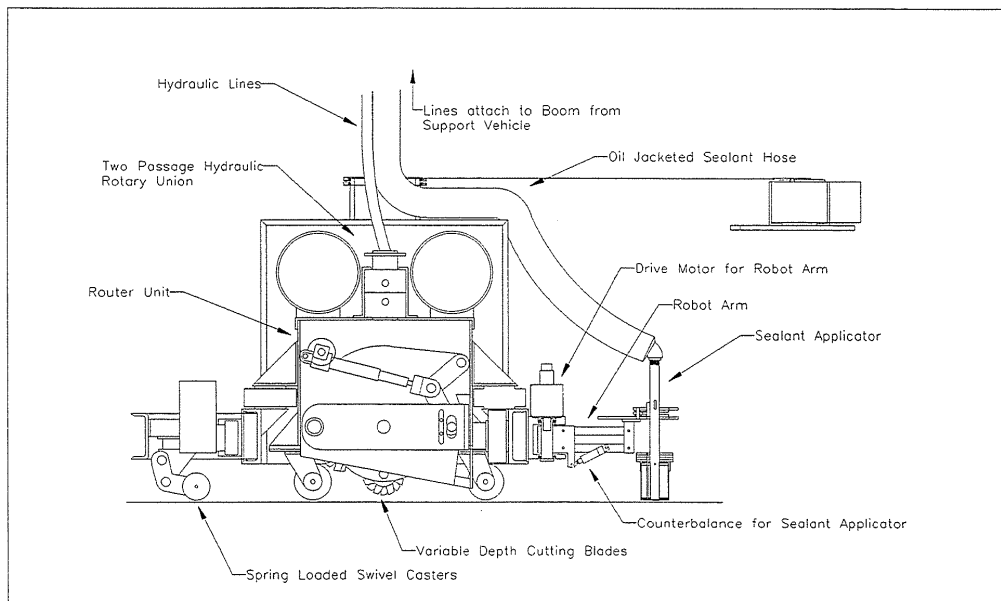
The router unit prepares cracks by cutting a channel which allows for increased penetration and adhesion of sealant. The design uses an existing impact router cutting wheel hydraulically powered with a remote power supply on the support truck. The driving motors provide the end effector forces necessary to move the router through the pavement. The router "up-mills" in order to both provide a high quality cut and to avoid the problem where the router can pull itself out of the roadway. Air springs are the only points of connection between the router unit and the complete TMRR. They provide support and dampen vibrations of the routing process with respect to other TMRR components.

The sealant applicator delivers hot thermoplastic sealant over the roadway. A part of its unique design is a pressurized reservoir that forces the sealant into the routed crack. The path generated by the laser sensor following a crack will be used for not only the router, but also the drive motor attached to the sealant applicator robot arm. Finally, to achieve proper down force of the sealant applicator, an air cylinder counterbalances the weight of the rotating robot arm and sealant applicator.

Figure 2-2 shows the front view of the fabricated TMRR. Figure 2-3 also shows the rear view of the TMRR including the rear arm assembly. A commercial liftgate is modified and attached to the back of truck as a transporting device of the TMRR. The TMRR is lifted up and held on the lifting platform while the truck is moving without sealing. Figure 2-4 shows the TMRR and the liftgate assembly at the back of truck.



(a) Top view



(b) Cutaway view (A-A)

**Figure 2-1. Drawings of Tethered Mobile Routing Robot**

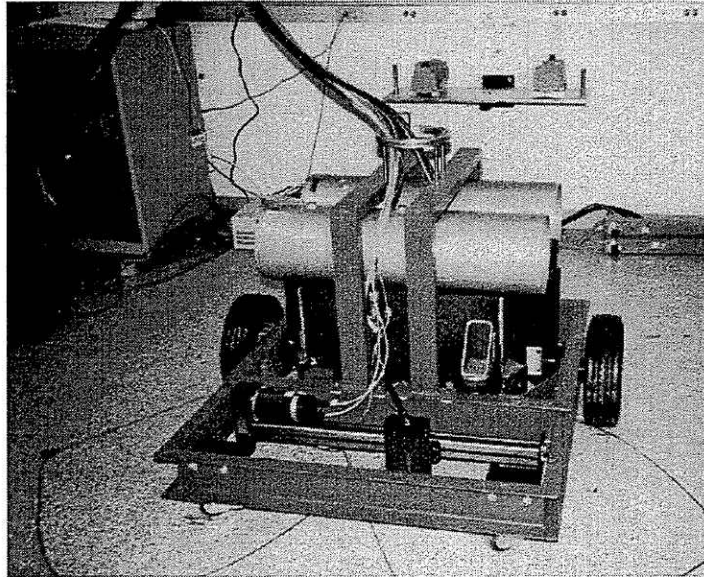


**Figure 2-2.** Front view of Tethered Mobile Routing Robot

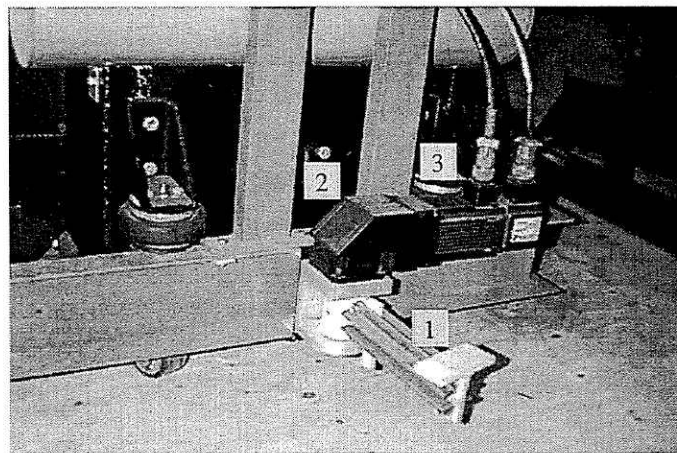


**Figure 2-3.** Rear arm assembly, 1: arm, 2: gear head, 3: BLDC motor

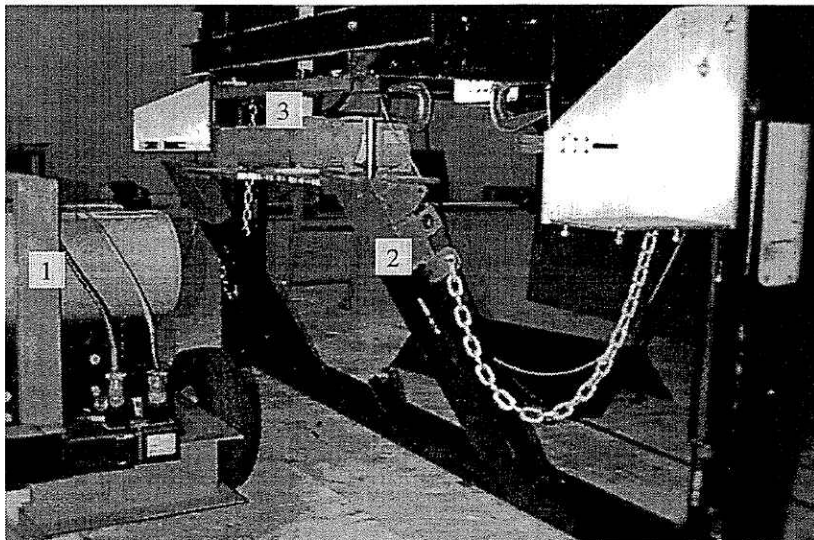


**Figure 2-4.** TMRR and lifter at the back of truck, 1: TMRR, 2: lifter, 3: CETs



## CHAPTER 3

### CONTROL OF TMRR

#### 3.1 Control Algorithms

The TMRR control system consists of three control modes, *Reference Path Tracking Control*, *Joystick Control*, and *Tracking Control with Laser Sensor*. One of these control modes can be selected depending on a required maintenance task. Figure 3-1 shows the block diagram of the control algorithm. Each of these control modes generates reference commands for mobile robot control and sealant arm control. Since the inertia of the sealant arm is much less than the one of the mobile robot platform, the dynamic coupling can be ignored. Therefore, the mobile robot platform and the sealant arm can be controlled independently. We have already developed several control algorithms for wheeled mobile robots using feedback linearization, sliding mode, and robust control techniques (Hong, et al., 1994; Hong, et al., 1997, b; Zhang, et al., 1997). Also, the sealant arm can be easily controlled with a Proportional and Integral control algorithm.

This report includes the kinematic model of the TMRR and the derivation of its trajectory tracking control algorithm. The TMRR consists of two components, the router blade on the robot platform and the sealant applicator at the end effector of the arm, which should be controlled to move along the crack path. The robot platform is driven by two driving wheels and the robot arm is separately actuated by an electric motor. There is dynamic interaction between the platform and the arm. However, the robot platform is designed to have a much heavier weight than the arm, so that the dynamic effect of the arm motion to the robot platform can be neglected; at the present design stage, the platform weight is expected to be over 200 kg and the arm weight is about 10% of it. The robot platform can therefore be controlled without considering the arm dynamics. The derivation of the tracking control is based on the work of Hong et al., 1997.

In order to describe the motion of the robot, two reference coordinate systems are introduced as shown in Figure 3-2. The *X-Y* coordinate system is attached to the support vehicle. The equations of motion are described based on the assumption that this coordinate system is stationary, so that it becomes a *global coordinate system* fixed with respect to the ground. The effect of the supporting vehicle's motion can be easily compensated later since it is primarily

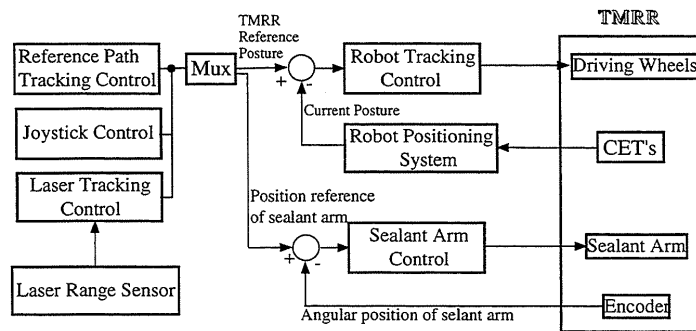


Figure 3-1. Block diagram of control software

translational in nature. The second coordinate system is the *body fixed system* attached to the TMRR with the  $x$  and  $y$  components representing the forward and lateral directions of the robot, respectively. The origin of the body centered coordinate system coincides with the control point  $C$  whose position is controlled to track the detected crack path; e.g., point  $C$  describes the router blade location. The control point  $C$  is placed on the center line, that is, on the  $x$  axis and on the center of the wheel baseline.

The elements of the posture vector include the translations in the  $x$  and  $y$  directions and the angular position  $\psi$ . After imposing the no slip condition, which forces the lateral velocity  $v_c$  to be equal to  $er_c$ , then the first derivative of the posture vector of the TMRR at point  $C$  in the global coordinate frame is written as

$$\begin{bmatrix} \dot{X}_c \\ \dot{Y}_c \\ \dot{\psi}_c \end{bmatrix} = \begin{bmatrix} \cos \psi_c & 0 \\ \sin \psi_c & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_c \\ r_c \end{bmatrix}, \quad (3-1)$$

where  $u_c$  represents the forward velocity of the TMRR and  $r_c$  represents the yaw rate of the robot. The posture  $\mathbf{X}_c \equiv (X_c, Y_c, \psi_c)^T$  of the robot at  $C$  in the global coordinate system is obtained after integrating Eqn. (3-1) given the linear and the angular velocities

of the robot. Point  $D$  denotes the desired control point location, and we denote the posture vector for the point  $D$  as  $\mathbf{X}_D$ . Also, let us denote the error posture in the body coordinates as  $\mathbf{x}_e$ . Then the error posture can be expressed as:

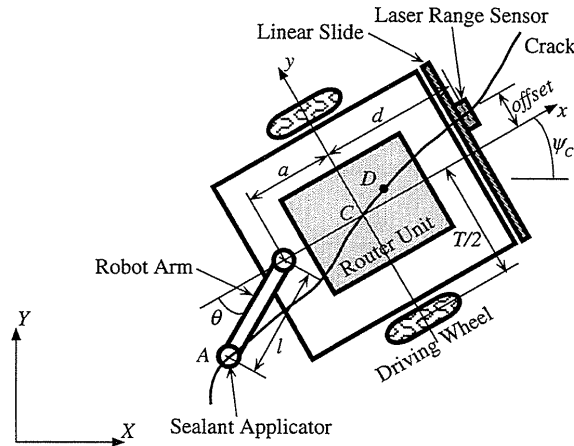


**Figure 3-2.** Schematic of WMR and Coordinate Systems

$$\mathbf{x}_e = \begin{bmatrix} \cos \psi_c & \sin \psi_c & 0 \\ -\sin \psi_c & \cos \psi_c & 0 \\ 0 & 0 & 1 \end{bmatrix} (\mathbf{X}_D - \mathbf{X}_C). \quad (3-2)$$

By differentiating the Eqn. (3-2) and substituting in Eqn. (3-1), we can obtain the following system equation:

$$\begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\psi}_e \end{bmatrix} = \begin{bmatrix} u_D \cos \psi_e \\ u_D \sin \psi_e \\ r_D \end{bmatrix} + \begin{bmatrix} -1 & y_e \\ 0 & -x_e \\ 0 & -1 \end{bmatrix} \begin{bmatrix} u_c \\ r_c \end{bmatrix} \quad (3-3)$$

where  $u_D$ ,  $r_D$  are the desired forward velocity and yaw rate of the robot at the point  $D$ . Our control problem is defined as finding a control law  $(u_c, r_c)^T$  such that, starting from an arbitrary location in a region  $\Omega$ , the state  $(x_e, y_e, \psi_e)^T$  tends to 0 as  $t \rightarrow \infty$ , given the nonlinear system described by Eqn. (3-3).

The system has three outputs and two control inputs; thus it is not square. Therefore, the coefficient matrix of the control input  $(u_c, r_c)^T$  is not invertable, which complicates the problem. Here, let us introduce a new variable,  $z_e$ , and positive constant  $c$ . The new variable can be used as a new state variable provided that the lemma is true: for  $z_e = y_e + c\psi_e$  and  $c > 0$ , both  $y_e$  and  $\psi_e$  go to zero, as  $z_e$  goes to zero. Proof has been shown in Hong et al., 1997. Consequently, by using the new state variable  $z_e$ , the equation of motion (3-3) becomes square as follows:

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}; t) + \mathbf{E}(\mathbf{x}; t)\mathbf{u} \quad (3-4)$$

where

$$\mathbf{x} = \begin{bmatrix} x_e \\ z_e \end{bmatrix}, \mathbf{f}(\mathbf{x}; t) = \begin{bmatrix} u_D \cos \psi_e \\ u_D \sin \psi_e + cr_D \end{bmatrix}, \mathbf{E}(\mathbf{x}; t) = \begin{bmatrix} -1 & y_e \\ 0 & -(x_e + c) \end{bmatrix}, \mathbf{u} = \begin{bmatrix} u_c \\ r_c \end{bmatrix}. \quad (3-5)$$

Finding a control law is fairly straight forward using the feedback linearization method which is commonly referred to as the computed torque method in robotics literature; see Fu et al. (1988). By selecting the control law as follows

$$\mathbf{u} = \mathbf{E}^{-1}(-\dot{\mathbf{f}} - \mathbf{K}\mathbf{x}), \quad (3-6)$$

then Eqn. (3-4) is transformed to

$$\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{0}. \quad (3-7)$$

Thus, the control is locally exponentially stable provided that the gain matrix  $\mathbf{K}$  is chosen such that the eigenvalues of the characteristic equations lie in the left-half plane.

The position  $\mathbf{X}_A$  of the end-effector of the arm in the global frame is expressed with the robot posture and the angular position of the arm itself, such that:

$$\mathbf{X}_A = \begin{bmatrix} X_c \\ Y_c \end{bmatrix} + \begin{bmatrix} \cos \psi_c & -\sin \psi_c \\ \sin \psi_c & \cos \psi_c \end{bmatrix} \begin{bmatrix} -(d + l \cos \theta) \\ -l \sin \theta \end{bmatrix}. \quad (3-8)$$

Since the dynamic interaction between the arm and the robot platform is negligibly small, the arm angular position is independently controlled with a Proportional & Integral (PI) control algorithm, such that the motor torque  $\tau$  is expressed as

$$\tau = K_p \theta_e + K_i \int \theta_e dt \quad (3-9)$$

where  $\theta_e$  is the angular position error of the arm and  $K_p$ ,  $K_i$  are proportional and integral control gains respectively.

### 3.2 Controller Architecture

The TMRR controller hardware is optimally designed in order to implement the developed control algorithms. The controller structure is shown in Figure 3-3. The main CPU of the controller is Pentium micro-processor based on PCI and ISA buses. The basic PC components, such as video card and hard disk controller, are housed in the PCI bus. Other peripheral boards necessary for control implementation are plugged into the ISA bus. The ISA is currently the most popular bus structure. Accordingly, commercially available hardware is available. The TMRR consists of two driving wheels and one sealant arm which are driven by Brushless DC motors. Accordingly, the TMRR controller should have motor controllers with as many node axes as the number of the total driving units. The motor controllers take  $\pm 10$  VDC analog signals as control commands, so that a multi-channel D/A converter board is used in order to interface them to the host computer. For the Joystick Control mode, an industrial type joystick is interfaced through an A/D converter. The ISA based encoder interface boards are used for the cable extension transducers and the joint encoder of the sealant arm. Also, the laser sensor system consists of ISA bus based boards which are an image-processing board and a digital signal processing (DSP) board. In addition, the controller is equipped with 15 ISA slots that can be used to expand controller capability for various control purposes.

Figure 3-4 illustrates signal wiring between each unit. The back panel of the control computer is shown in Figure 3-5, which identifies each signal cable. Figure 3-6 shows the motor drives, the first drives, DM30's, are for the driving wheels, the third drive, DM20, is for the rear arm, and the last drive is for the linear slide of the laser sensor system. Also, Figure 3-7 shows power wiring on the back panel of the controller cabinet. The labels on the power circuit

components shown in Figure 3-8 are used to identify the circuit components in the Figure 3-9. The numbers on the switches shown in Figure 3-8 correspond to the picture of the controller front panel shown in Figure 6-3.

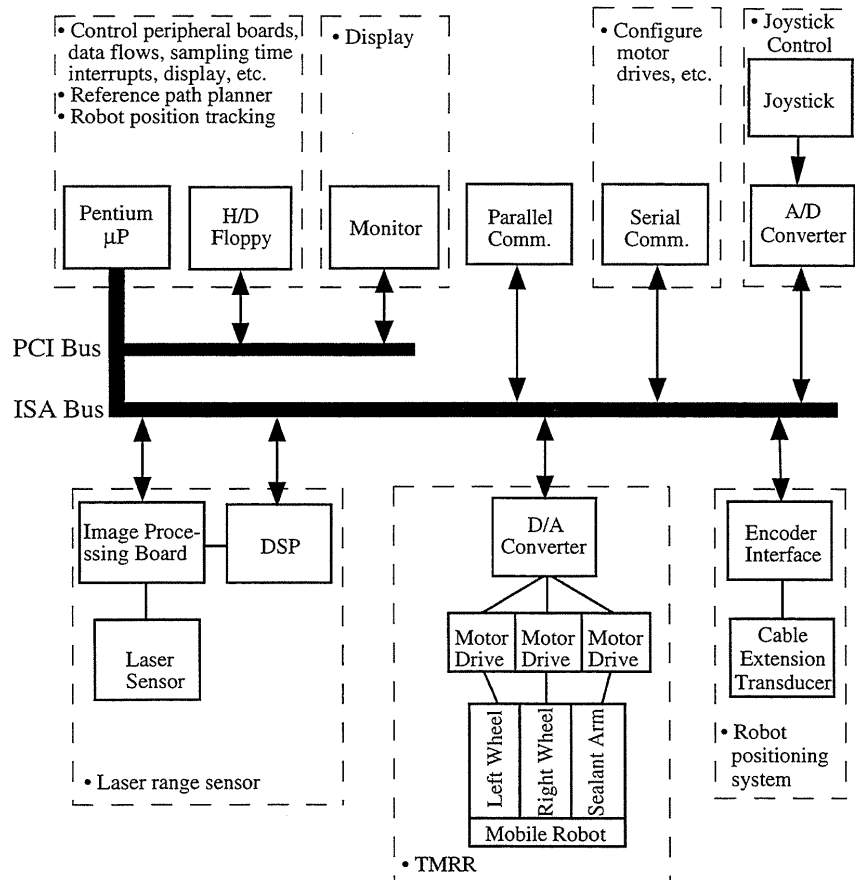


**Figure 3-3.** Block diagram of control hardware

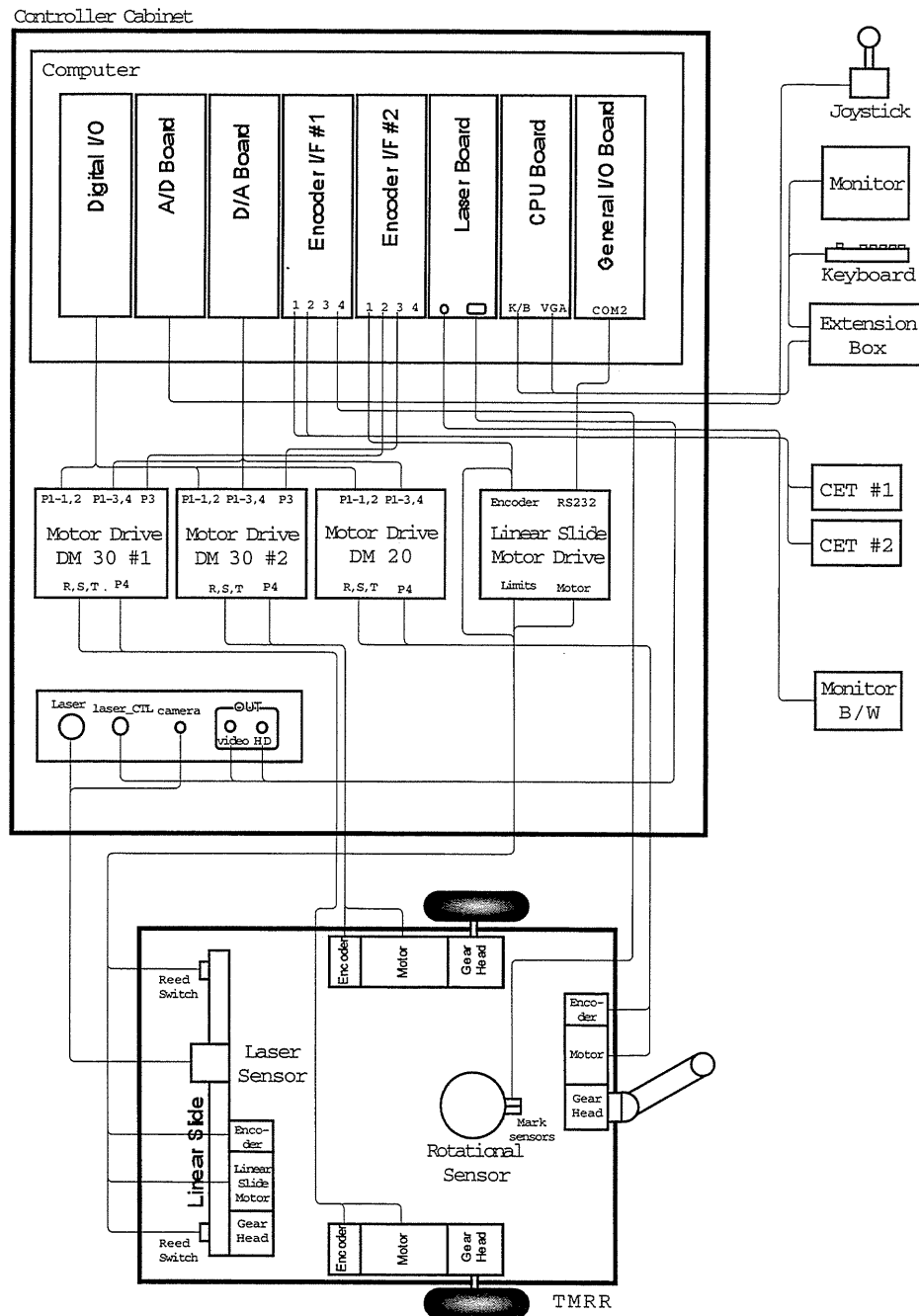


Figure 3-4. Overall wiring diagram of TMRR controller

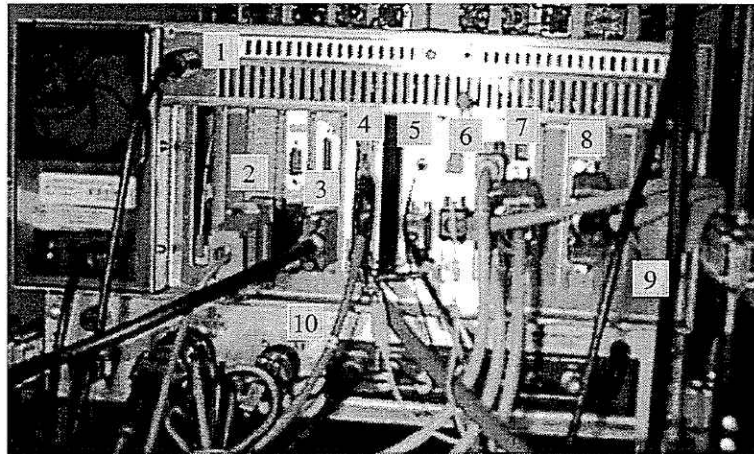


**Figure 3-5.** Back of computer, 1: keyboard connector, 2: COM1, 3: monitor cable, 4: encoder interface board #2, 5: laser processing board, 6: encoder interface board #1, 7: A/D converter board, 8: D/A converter board, 9: digital I/O board, 10: laser controller

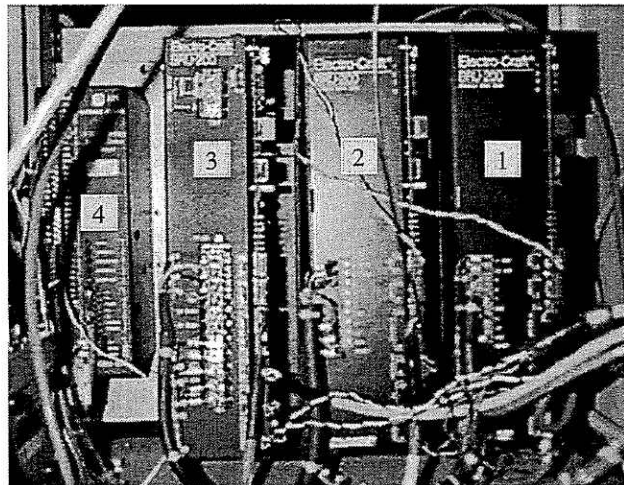


**Figure 3-6.** Motor drives, 1: DM30 #1, 2: DM30 #2, 3: DM20, 4: linear slide motor drive

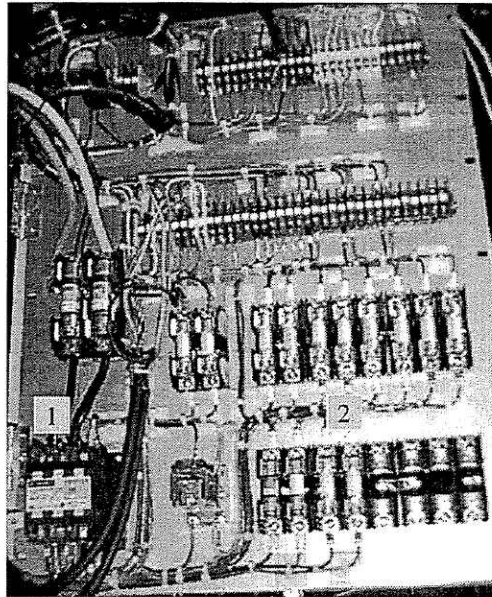


**Figure 3-7.** Power wiring on cabinet back panel, *1: magnetic contactor, 2: fuse blocks*



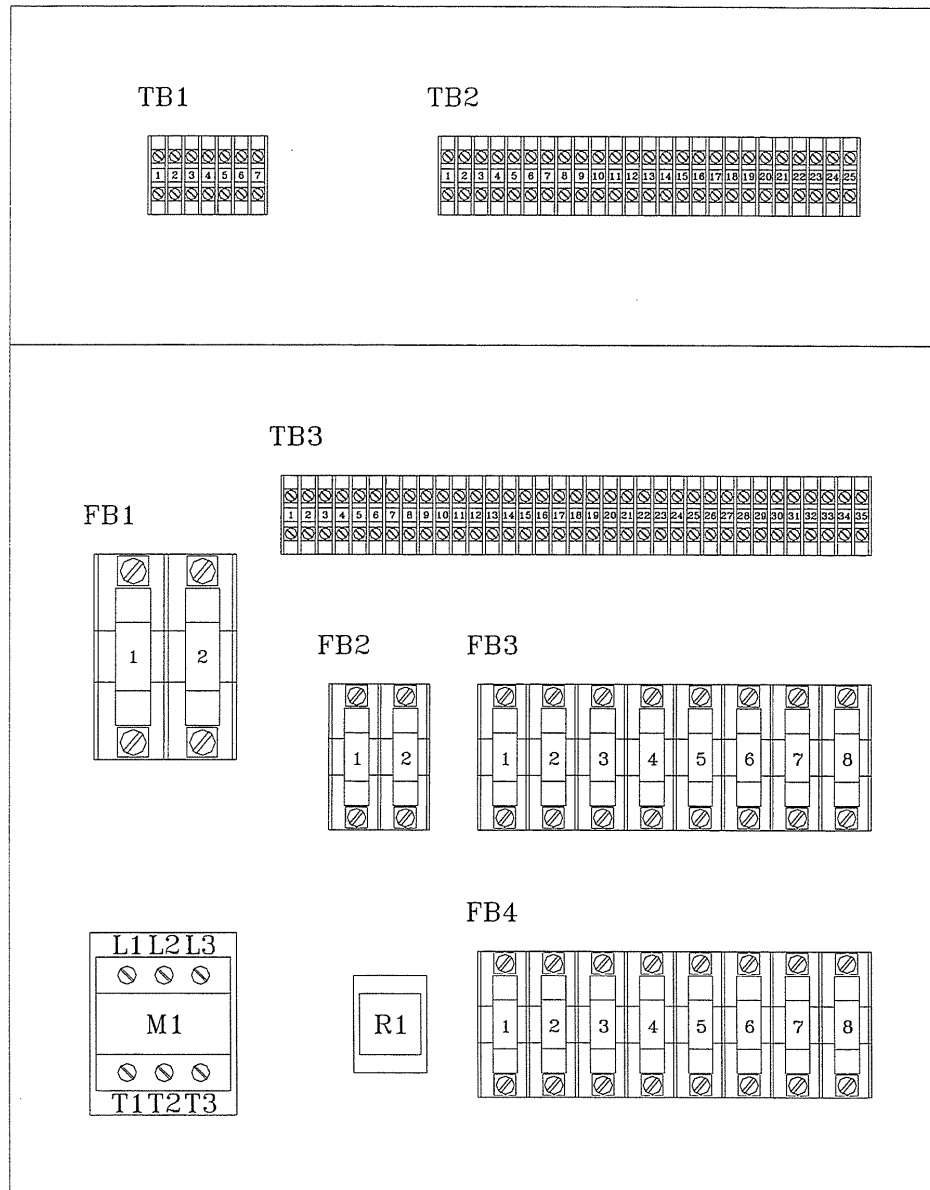


**Figure 3-8.** Power wiring components on cabinet back panel

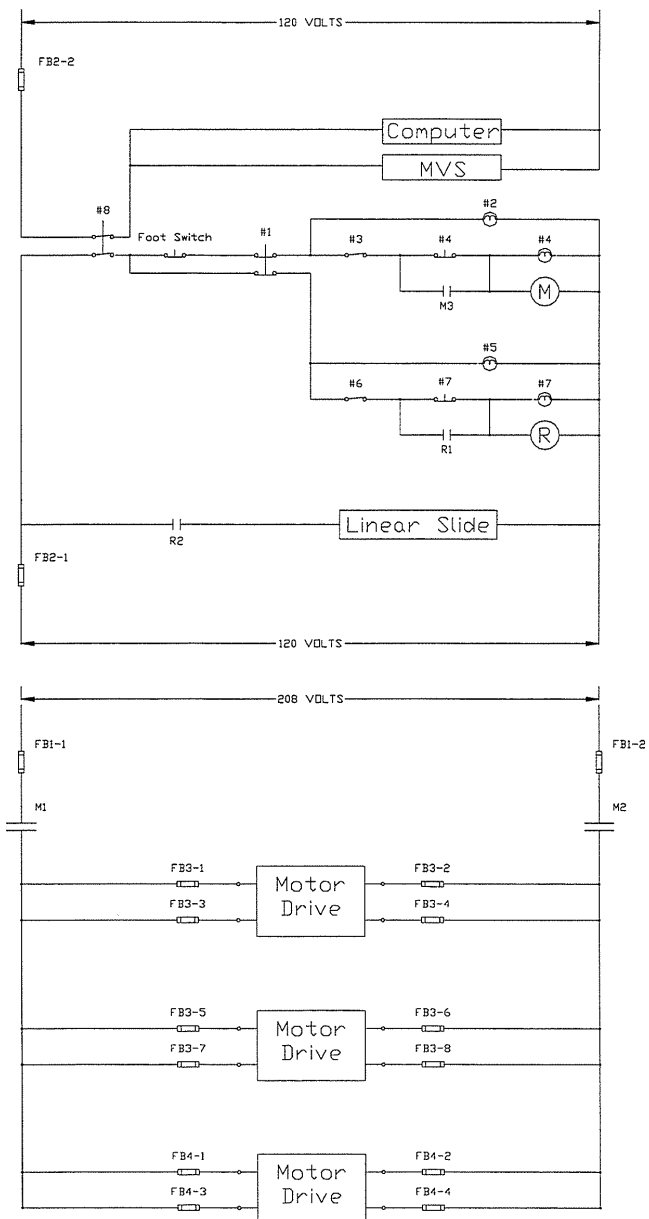


**Figure 3-9.** Power circuit of TMRR

## CHAPTER 4

### ROBOT LOCALIZATION SYSTEM

The motion of the robot is controlled relative to the support vehicle, so that a relative position tracking system is essential. Based on the intended applications of the robot system and the corresponding tracking system requirements, a new approach for robot localization has been developed (Hong, et al., 1995).

The developed sensor approach is novel in that it uses new technology in the form of cable-extension transducers (CETs) to determine robot position. CETs are linear-displacement sensors which produce electrical signals proportional to the travel of their extension cables. CETs achieve a 0.01% accuracy for up to approximately a 40 meter range, and they are relatively robust, inexpensive, and easy to use compared to other approaches. CETs do require a physical connection between the support vehicle and the mobile robot, but the support vehicle must provide power and materials, and thus a physical connection already exists.

The configuration of the sensor system is shown in Figure 4-1. The cables from both cable-extension transducers are passed around the pulleys and are attached to the robot. The pulleys are required to allow the cable to exit from the transducer with the same orientation, which is a necessity, yet locate an arbitrary position in the workspace. Also, the picture of the assembled sensor system is shown in the Figure 2-4.

The position equations are derived based on the parameters shown in the schematic diagram of the sensor system, Figure 4-1. The cables from both cable-extension transducers are passed around the pulleys A and B and are attached to point P on the robot. The pulleys are required to allow the cable to exit from the transducer with the same orientation, which is a

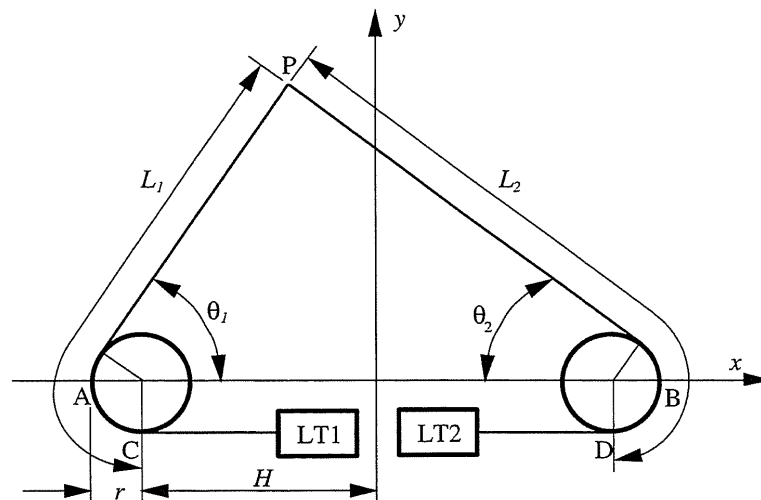


**Figure 4-1.** Schematic diagram of CET sensor system  
necessity, yet locate an arbitrary position P in the workspace. The size of the pulleys in the figure are exaggerated for illustrative purposes.

The pulleys' diameters should be determined based on space constraints and the system's expected life. While this is a slow speed application, the cable's bending stresses will still dictate the life of the cable; i.e., cable fatigue due to the cyclic bending stresses will ultimately cause the cable to fail. In general, a relatively large pulley diameter compared to the cable diameter is necessary. In this application, there is no need to use a pulley diameter significantly larger than the diameter of the CET's spool.

The coordinate system is assigned as follows:  $x$  passes through the centers of both pulleys and its origin is midway between the two pulleys. The cable length is defined as the distance of P from the point C or D on the pulley circumference as shown in Fig. 4-1. This augmented cable length can be easily obtained by appropriately resetting the counter of the CETs or adding an offset value. Due to the pulley effect, it is impossible to find an explicit form for the position equation of point P. Thus, parametric variables,  $\theta_1$  and  $\theta_2$ , which are the inner angles formed by the  $x$ -axis and the cables, are used. With these parameters, the following relationships are obtained:

$$L_1 - r(\pi - \theta_1) - (y_p - r \cos \theta_1) / \sin \theta_1 = 0 \quad (4-1)$$

$$y_p \cot \theta_1 - H - x_p - r / \sin \theta_1 = 0 \quad (4-2)$$

$$L_2 - r(\pi - \theta_2) - (y_p - r \cos \theta_2) / \sin \theta_2 = 0 \quad (4-3)$$

$$y_p \cot \theta_2 - H + x_p - r / \sin \theta_2 = 0. \quad (4-4)$$

In these equations,  $x_p$  and  $y_p$  are the dependent variables that need to be determined. The input variables are the lengths of each cable,  $L_1$  and  $L_2$ . However, we cannot reduce the equations and get explicit equation forms for  $x_p$  and  $y_p$  in terms of  $L_1$  and  $L_2$  due to the nonlinearities with respect to the parametric variables  $\theta_1$  and  $\theta_2$ . Consequently, the problem at hand is to numerically solve the nonlinear simultaneous equations (4-1) through (4-4) to obtain the four unknowns  $x_p$ ,  $y_p$ ,  $\theta_1$ , and  $\theta_2$  given  $L_1$  and  $L_2$ . The detailed schemes to solve these equations in real-time fashion are discussed in Hong, et al., 1995.

The general plane motion of a rigid body is described with three variables;  $x$ ,  $y$  position and  $\theta$  orientation. The position of the robot was determined by solving the above equations. In order to obtain the orientation of the robot, the rotational sensor system shown in the Figure 4-2 is installed on the robot center. The rotational sensor system has two rings mounted on ball bearings. The CET cables are attached on the rings, so that the rings freely turn due to cable tension as the robot moves around. The orientation of the robot is therefore determined by reading the rotation of one ring. In the Figure 4-2, the mark and mark sensors are provided to read the angular rotation of the ring. Since any frictional force hinders free rotation of the ring, the non-contact mark sensors are utilized. In order to detect rotational direction, two sensors and two rows of marks are placed in the way that  $90^\circ$  phase difference exists between each other. This also makes it possible to treat the sensor signals as quadrature inputs. The sensor signals are boosted up with differential line driver circuit in order to remove electric noise.

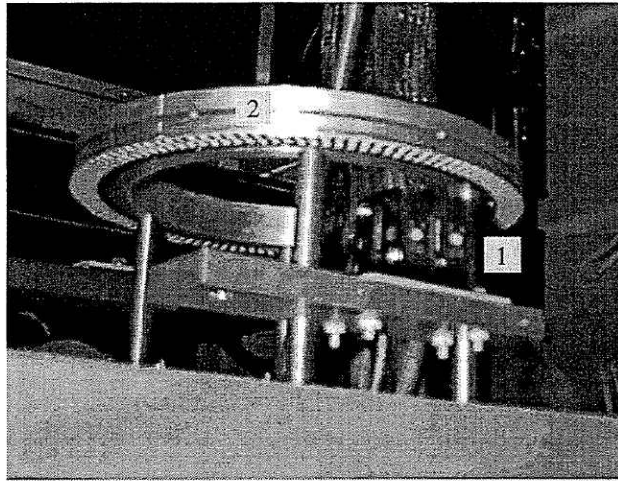


**Figure 4-2.** Rotational sensor assembly, *1: mark sensor, 2: mark*

## CHAPTER 5

### CRACK FINDING SENSOR

Based on the study of a variety of sensor technologies, Krulewich and Velinsky (1992) selected a laser range finder based sensor for their crack detecting device and showed its ability to identify cracks in both Asphalt Concrete (AC) and Portland Cement Concrete (PCC) pavements. The same laser range finder sensor is attached at the front of the TMRR platform in this work as shown in Figure 5-1. The laser range finder sensor scans the road surface with a narrow line of structured light produced through a cylindrical lens. It provides a line scan of the profile of the road surface. The field of view of the laser range sensor is about 5-8 cm. Also, the laser range sensor cannot be installed close to the control point due to the physical dimension of the router unit and also due to the debris produced by the router blade. In order to cope with this limitation on the small field of view, a linear slide is provided on which the laser range sensor is attached. The laser range sensor travels back and forth on the slide in a wide range,  $\approx 50$  cm. The laser range sensor is controlled to always lie on the crack position detected at the previous sampling time, so that the sensor can detect the current crack with the small field of view. The sensor system and crack detection algorithms are detailed in Matsumoto, 1996.

The  $y$  component of the detected crack position in the body fixed coordinate frame is the *offset* value, the distance between the sensor center (which aligns with the centerline of the mobile robot) and the crack reservoir center. The global coordinates of the detected crack position are then obtained by coordinate transformation. The distance  $d$  of the laser range sensor from the origin of the body coordinates in the  $x$  direction is fixed. The following equation expresses the crack position in the global coordinate system based on the robot position, the sensor position, and the sensed offset value:

$$\begin{bmatrix} X_i \\ Y_i \end{bmatrix} = \begin{bmatrix} X_G \\ Y_G \end{bmatrix} + \begin{bmatrix} \cos \psi_{G_i} & -\sin \psi_{G_i} \\ \sin \psi_{G_i} & \cos \psi_{G_i} \end{bmatrix} \begin{bmatrix} d \\ offset \end{bmatrix} \quad (5-1)$$

where the subscript  $i$  denotes the  $i$ -th sampling instance and  $(X_{G_i}, Y_{G_i})^T$  is the position vector of the TMR. With the time function of  $X_i$  and  $Y_i$  in discrete form, the tangent angle of the crack path is obtained as

$$\psi_i = \text{atan} \left( \frac{Y_i - Y_{i-1}}{X_i - X_{i-1}} \right). \quad (5-2)$$

The posture vector of the crack,  $(X_i, Y_i, \psi_i)^T$  is formed from Eqns. (5-1) and (5-2). This posture vector is stored in buffer memory at each sampling time and utilized to determine the reference posture for the robot tracking control.

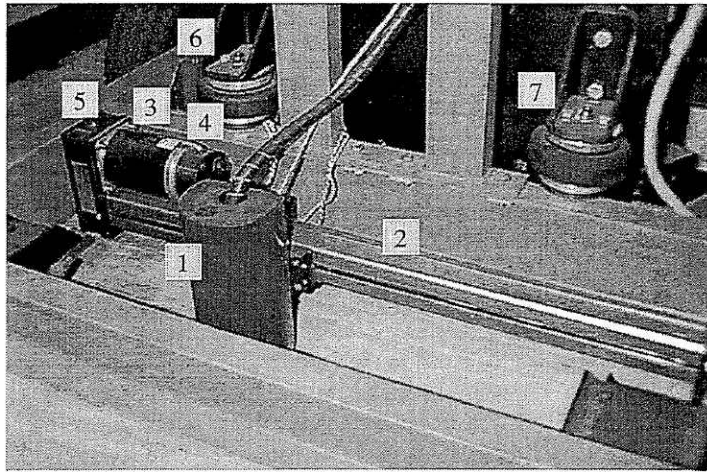


**Figure 5-1.** Laser sensor assembly, 1: laser sensor, 2: linear slide, 3: stepper motor, 4: encoder, 5: gear head, 6,7: air springs

## CHAPTER 6

### OPERATIONAL INSTRUCTIONS

#### 6-1. Liftgate Operation

The liftgate operation consists of four different basic modes, Crack sealing/routing mode, Load/unload mode, Move-ahead mode, and Transport mode. The TMRR should be held on the lifting platform at 1.4 m (4.5 ft) up-position from the ground while it is being transported over long distances as shown in Figure 6-1 (c). In this transport mode, the CET cables should be disconnected from the TMRR. Also, the secondary support frame should be slid out and tied to the TMRR. The Move-ahead mode is used for short distance travel. In this mode, the TMRR is lifted up about 30 cm (1 ft) from the ground without disconnecting the CET cables and without tying the TMRR to the lifting platform. The Load/unload mode is used to load/unload the TMRR from the liftgate. In this mode, the lifting platform should make contact on the ground. In the Crack sealing/routing mode, the lifting platform should be folded (that is, up-right position), since the platform may be inside of the TMRR's workspace.

Figure 6-2 shows the liftgate control pendent. The first switch from the top is used to lift the liftgate up and down, the second switch is used to lock/unlock the liftgate, and the third switch is used to tilt up and down the lifting platform.

#### 6-2. Descriptions of Switches on Controller Cabinet

Figure 6-3 shows the front panel of the controller cabinet. This section describes the functions of each switch on the controller cabinet as follows.

1. Emergency shutoff switch: It is a mushroom switch to shutoff motor power in the event of an emergency. It does not turn off the computer power.

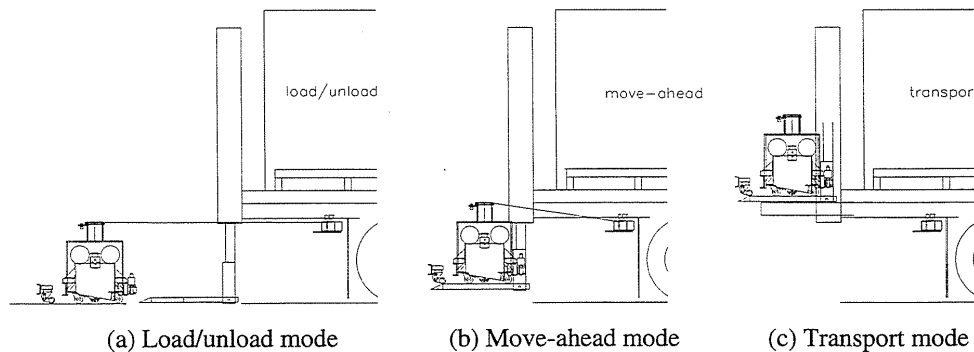


**Figure 6-1.** Illustration of TMRR liftgate operating modes



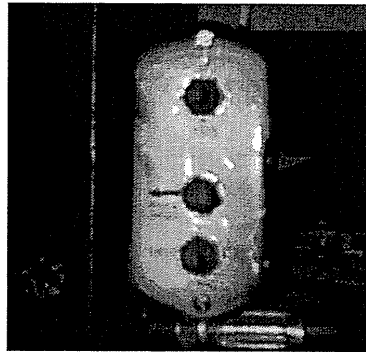


**Figure 6-2.** Liftgate control pendent

2. Motor controller power indicator light: It indicates that the motor controller power is ready to be turned on. It does not necessarily mean that the motors are already turned on.
3. Motor controller off/enable switch: Only when this switch is on, the motors can be turned on (with the motor controller on indicator light/push button (#4 in the Figure 6-2)). It should be switched to the right position to turn on.
4. Motor controller on indicator light/push button: It is a push button to turn on the motor power. It also indicates whether the motor power is on or not.
5. Linear slide power indicator light: It indicates that linear slide power is ready to be turned on. It does not necessarily mean that the linear slide is already turned on.
6. Linear slide off/enable switch: Only when this switch is on, the linear slide can be turned on (with the linear slide on indicator light/push button (#7 in the Figure 6-2)). It should be switched to the right position to turn on.
7. Linear slide on indicator light/push button: It is a push button to turn on the motor power. It also indicates whether the motor power is on or not.
8. Master power switch: It is a keyed switch to turn on all power. Anything in the controller cabinet cannot be turned on when this is off (left position).
9. Computer power switch: Computer power switch.
10. Laser controller power push button: It turns on the laser controller power.
11. Laser controller test push button: It is used to test the laser controller.
12. Laser controller master switch: It is a keyed master switch for the laser controller.
13. Laser indicator light: It indicates that the power is going through the laser.
14. Laser current control knob: It controls the amount of current going through laser.

### 6-3. TMRR Operation

This section describes how to operate the TMRR with the basic knowledge described in the previous section. Before TMRR operation, the liftgate should be in the Crack sealing/routing mode (that is, the TMRR is on the ground and the lifting platform is in the up-right position) and all power cables should be properly connected. The operation procedures will be described step



**Figure 6-3.** Front panel of controller cabinet, 1: emergency shutoff switch, 2: motor controller power indicator light, 3: motor controller off/enable switch, 4: motor controller on indicator light/push button, 5: linear slide power indicator light, 6: linear slide off/enable switch, 7: linear slide on indicator light/push button, 8: master power switch, 9: computer power switch, 10: laser controller power push button, 11: laser controller test push button, 12: laser controller master switch, 13: laser indicator light, 14: laser current control knob

by step in the following sub-sections. First, power-up procedures will be explained. Then, control program initialization and three different control modes will follow.

#### A. Power-Up

1. Turn on the UPS which is placed in front of the controller cabinet. The computer power is supplied through the UPS.
2. Turn on the master power switch (#8 in the Figure 6-3). Make sure that the emergency shutoff switch (#1 in the Figure 6-3) and the emergency foot switch (Figure 6-4) are in pull position. Then, the indicator lights #2 and #5 in the Figure 6-3 should be lit.
3. Make sure that the motor controller off/enable switch should be at off position. This is because the command signal for the motor controller should be initialized before the motor power is supplied and this is done by the computer boot-up routine. Then, Turn on the computer power switch (#9 in the Figure 6-3) and the computer monitor.

#### B. TMRR Control Program Initialization

1. The control program is in the directory 'C:\TMRR'. Go into that directory and run 'TMRR'.
2. You will get the message, "Place the robot at the initial position and type y when ready". Then, place the TMRR at the index position and press 'y'.
3. Then, you will get the prompt, "TMR>>". Now, you are ready to run the following commands.

---

? : Help screen  
a : Joystick control including rear arm  
b : Clear rear arm control flag  
c : Read CET  
f : Turn off relay  
h : Halt all motors  
j : Joystick control (not include rear arm)  
k : Swing rear arm with joystick  
l : Laser tracking control  
o : Turn on relay  
p : Preprogrammed path  
q : Quit!  
r : Set rear arm position command (0-120000 = 0-180degree)  
s : Send speed commands to motor drives  
v : Return to default video mode

4. Turn the motor controller off/enable switch to the right and push the motor controller on indicator light/push button. Then, the push the motor controller on indicator light/push button will be lit, which means the motor controller is powered up.

C. Joystick Control

1. Type 'j' right after the prompt to run the joystick control mode.
2. Type 'o' to enable the motor drives.
3. Figure 6-5 shows the joystick control device.
4. Type any key to return the main prompt "TMR>>".

D. Pre-programmed Path Following

1. Place the robot around (-40, 70) with approximately 70° using the joystick control mode.
2. Type 'o' to enable the motor controllers.
3. Type 'b' to run the tracking control mode, then, the robot will start to follow the path.
4. Type any key to stop the robot. Then, you will get the main prompt "TMR>>".

E. Laser Tracking Control

1. You have to turn on the laser controller first. To do that, turn on the laser controller master switch (#12 in the Figure 6-3) and push the laser controller power push button (#10 in the Figure 6-3).
2. Place the robot on the starting position of a crack using the joystick control mode.
3. Type 'm' to run laser control mode and wait for a while until the laser sensor is initialized and stop on the crack.
4. You can stop the robot by hitting any key while operation.

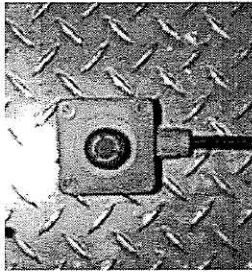


**Figure 6-4.** Emergency foot switch

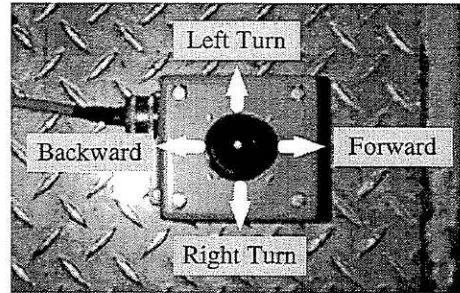


**Figure 6-5.** Joystick

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## CHAPTER 7

### CONCLUSION

The Tethered Mobile Routing Robot (TMRR) has been developed at the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California at Davis in order to automate the highway crack sealing operation. The TMRR is a differentially steered wheeled mobile robot with a centrally located router and articulated sealant head. A laser range sensor is installed from the front of the robot to allow for automated crack following. The sensor is slide mounted to provide the necessary field of view. A support vehicle provides all power and materials through the use of a tether, and also contains a vision based sensing system for crack identification. The robot position relative to the support vehicle utilizes a cable extension transducer based system.

The development effort has involved development of system design concept evolved from the TMR concept, improvement of sensor systems including robot localization system using CETs and crack sensing system, design and construction of a prototype TMRR attached to the Automated Crack Sealing Machine (ACSM). Also, the controller hardware was appropriately constructed and the control algorithm developed in the previous stage was successfully implemented on the robot.

This document has concisely reviewed some of the important aspects of the TMRR system development. The interested reader is referred to the noted technical reports and documents for additional detail.

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## CHAPTER 8

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APPENDIX A  
COMPONENT LIST

Table 1. Component list

| Name                                     | Model                           | Manufacturer                    | E.t.c                            |
|------------------------------------------|---------------------------------|---------------------------------|----------------------------------|
| Pentium CPU Board                        | SB586P                          | Industrial Computer Source      | Pentium single board computer    |
| A/D Converter Board                      | CYDAS 8JR-AO                    | CyberResearch, Inc.             |                                  |
| D/A Converter Board                      | CYRDDA 06                       | CyberResearch                   |                                  |
| Encoder Interface Board                  | M5312B                          | Industrial Computer Source      | 4 channel encoder interface card |
| PC to Incremental Encoder Interface Card | PC7166                          | U.S. Digital Co.                | 4 channel encoder interface card |
| Digital I/O Board                        | CYRDIO 32                       | CyberResearch                   |                                  |
| Laser Sensor                             | Laser Vision Sensor MVS-30      | MVS Modular Vision Systems Inc. |                                  |
| BLDC Motor                               | S-3016                          | Electro-Craft                   | Brushless DC motor               |
| BLDC Motor                               | S-4050                          | Electro-Craft                   | Brushless DC motor               |
| BLDC Motor Drive                         | DM-20                           | Electro-Craft                   | Motor drive for S-3016           |
| BLDC Motor Drive                         | DM-30                           | Electro-Craft                   | Motor drive for S-4050           |
| Linear Slide Assembly                    | Linear Positioner               | JASTA                           |                                  |
| Gear Head                                | RA90-100                        | Bayside                         | 100:1 ratio                      |
| Cable Extension Transducer (CET)         | PT9150                          | Celesco                         |                                  |
| Joystick                                 | Induction Type Joystick Control | Maurey                          | Allied Electronics, Co.          |
| Industrial PC Enclosure                  | 7500                            | Industrial Computer Source      | 15 slots enclosure               |
| Subminiature Mark Sensor                 | MQ-VD2AR-DC12-24V               | Aromat                          |                                  |



APPENDIX B  
TMRR CONTROL PROGRAM

```

//////////////////////////////////////
//                                     //
// TMRR CONTROL PROGRAM               //
//                                     //
// AUTHOR: DAEHIE HONG                //
//                                     //
// REVISION:                          //
//     timer interrupt & CET real-time calculation //
//     joystick control including rear arm, sampling rate for the joystick //
//     control is 25Hz (=40ms).       //
//     pre-programmed path.           //
//     timer interrupt routine is replaced with new one (no assembly parts). //
//////////////////////////////////////

#include <process.h>
#include <stdio.h>
#include <bios.h>
#include <conio.h>
#include <string.h>
#include <math.h>
#include <dos.h>
#include <graph.h>
#include <stdlib.h>

#include "m5312.c"
#include "ibm.h"

#define TMR_INTR

/*****
/* Define parameters */
/*****
#define S_limit 4000 // speed limit for driving wheels
#define Sr_limit 500 // speed limit for rear arm

#define rp 2.037 // CET pulley radius
#define HH 17 // CET base length
#define DD 38.074 // 2*(HH+rp)
#define DD2 19.037 // DD/2
#define Thr0 0.8142 // =46.65degree, initial angle for robot
// angular position measurement
#define IL1 31.633 // initial cable lengths
#define IL2 31.633
#define MaxEncoder 16777216 /* Maximum number of the 24 bit counter */
#define MaxEncoder2 8388608 /* and half of it */
#define Sensitivity 1004.804 /* 251.201 pulses per inch */

#define PI 3.141592654

```

```

#define cot(a) (cos(a)/sin(a))
#define NTRIAL 5
#define TOLX 1.0e-6
#define N 4
#define TOLF 1.0e-6

#define RARM_LENGTH 12 // rear arm length = 12"

/*****
/* Define parameters for A/D converter */
*****/
#define BASE 0x200
#define ADC_LSB BASE
#define ADC_MSB BASE + 1
#define ADC_START BASE + 1
#define ADC_CONTROL BASE + 2
#define ADC_STATUS BASE + 2
#define ADC_CH_0 0
#define ADC_CH_1 1

/*****
/* Define parameters for screen display */
*****/
#define dashed 0xA0A0
#define solid 0xFFFF
#define red 4
#define cyan 3
#define green 2
#define yellow 14
#define white 7
#define lt_blue 9
#define brt_green 0
#define lt_magenta 13
#define black 0
#define blue 1

#define no_vert_lines 18
#define xconstant 35
#define no_horiz_lines 11
#define yconstant 35
#define pi 3.1415927
#define cga 2.0833333 /* distance from front of TMR to applicator in inches */
#define cgb 0.416667 /* distance from rear of TMR to applicator in inches */

/*****
/* Define parameters for sound (timer, speaker) */
*****/
#define TIMER_FREQ 1193180L
#define TIMER_COUNT 0x42
#define TIMER_MODE 0x43
#define TIMER_OSC 0xb6
#define OUT_8255 0x61
#define SPKRON 3

/*****

```

```

/* Define function prototypes */
/*****/
void relay_on(int);
void relay_off(int);
void Send_Velocity_Commands(int, int);
void Send_Velocity_RearArm(int);
float AD_convert(int);
void init_joystick(void);
void joystick(int);
void Stop_Motors(void);
long Read_Rear_Encoder(void);
void joystick_rear(int);
void cet_rt(float *, float *, float *);
void get_CET(float *, float *, float *);
void usrfun(float, float);
void mnewt(int,int,float,float, float,float);
void lubksb(int,int *);
float aatan(float, float, float, float);
int Tracking_Control(void);
void Help_Screen();
void draw_tmr(float, float, float, int, int, int, int, int, int);
void create_replace_grid(void);
void mark_origin(int, int);
void set_workspace(void);
void draw_tmr_trajectory(void);
void sound_on(unsigned);
void sound_off(void);

#ifdef TMR_INTR
void (interrupt far *OldTimerVect)(); /* save original vector */
void interrupt far Timer_Intr_SR(void);
void init_timer(void);
void restore_timer(void);
void settimer( long ms );
long ReadClock();
#endif

#define ESC 27
extern void sendline(unsigned char *s);
extern void rsout(unsigned char ch);

float Volt0_i, Volt1_i; /* initial voltages of joystick */
int BaseAddr = 0x320; /* Base Address for D/A board */

// parameters for timer interrupt
long int no_ticks=0L;
long int ms=5L;

// parameters for rear arm position control
long int pos_c, pos_e;
long int pos_r=0;
long int pos_e_int=0;
int RA_flag = 0;

// parameters for real-time calculation of CET system

```

```

float x[N+1], alpha[N+1][N+1], bet[N+1];

// buffer for robot posture
#define BL      2000
float Xcc[BL], Ycc[BL], Tcc[BL];
int bf=0, bp=0, nbf=0, nbp=0, bp1=0, bp2=0, bpo=0;
int movef_flag=0, outside_arm=0, inside_arm=0, bf_bp=0;

int x_pos, y_pos, x0, x1, x2, x3, x4, yy0, yy1, y2, y3, y4;
int tx1, tx2, tx3, tx4, tx5, tx6, tx7, tx8;
int ty1, ty2, ty3, ty4, ty5, ty6, ty7, ty8;

main()
{
    int rn,wl,wr,ra;
    char ch, cc1;
    long    d_cnt; /* counter values          */
    long    tmp_pos_r;
    float    Xc,Yc,Tc;      // Robot Posture w.r.t. fixed frames
    float    xcr, ycr,xcr1,ycr1; // Robot posture w.r.t. rear arm frames
    long int  begtime, no_sampling=0;
    float    cosT,sinT,radarm, arm_angle;
    int      loop_count, bpp;
    int      ik;

    relay_off(0);
    relay_off(1);
    relay_off(2);
    Stop_Motors();

    init_joystick(); /* get initial position of joystick */

#ifdef TMR_INTR
    init_timer();
    settimer(ms);    // generate timer interrupt every ms (default=5) ms
#endif

    /** initialize each encoder - see manual for detail parameter setting */
    init_encoder(Axis_A, MCRE, ICR, OCCR, QR, enc_base); /* init a */
    init_encoder(Axis_B, MCRE, ICR, OCCR, QR, enc_base); /* init b */
    init_encoder(Axis_C, MCRE, ICR, OCCR, QR, enc_base); /* init c */
    init_encoder(Axis_D, MCRE, ICR, OCCR, QR, enc_base); /* init d */
    printf("\n");
    do {
        printf("\rPlace the robot at the initial position and type y when ready");
        cc1 = getchar();
    }while( cc1 != 'y');

    load_cntr(WR_ALL, 0l, enc_base); /* zero counters of encoders on linkage */

    do
    {
        printf("\nTMR>> ");
        ch = getchar();

```

```

switch (ch) {
    case '?':
        Help_Screen();
        break;

    case 'a': // joystick control including rear arm,
        RA_flag = 1;
        begtime = ReadClock();
        no_sampling = 0;
        while( !kbhit() ) {
            joystick(1); // forward motion only
            cet_rt(&Xc,&Yc,&Tc);

            if (RA_flag) {
                if (bf >= BL) {
                    bf = 0; // if buffer front >= buffer length, return to buffer
                    nbft++; // start & increase number of turns
                }
                if (movef_flag) { // if the robot moves forward,
                    Xcc[bf] = Xc; // store robot posture in buffer.
                    Ycc[bf] = Yc;
                    Tcc[bf] = Tc;
                    bf++;
                }

                // printf("\n-----1\n");
            }

            cosT = cos(Tc);
            sinT = sin(Tc);
            inside_arm = 0;
            outside_arm = 0;

            // printf("\n-----2\n");

            // if (bp == BL) { bp = 0; nbp++; }

            xcr = (Xcc[bp] - Xc)*cosT + (Ycc[bp] - Yc)*sinT;
            ycr = -(Xcc[bp] - Xc)*sinT + (Ycc[bp] - Yc)*cosT + 16.0;
            xcr = -xcr;
            ycr = -ycr;
            radarm = sqrt(xcr*xcr + ycr*ycr);
            // printf("\n%f %f %f\n",xcr,ycr,radarm);
            if ( (ycr > 0) && (radarm >= RARM_LENGTH) ) {
                outside_arm = 1;
                inside_arm = 0;
                while(!inside_arm) {
                    bp++;
                    if (bp == BL) { bp = 0; nbp++; }
                    xcr = (Xcc[bp]-Xc)*cosT + (Ycc[bp]-Yc)*sinT;
                    ycr = -(Xcc[bp]-Xc)*sinT + (Ycc[bp]-Yc)*cosT +

16.0;

                    radarm = sqrt(xcr*xcr + ycr*ycr);
                    if (radarm < RARM_LENGTH) {
                        inside_arm = 1;
                        xcr = -xcr;
                        ycr = -ycr;

```

```

arm_angle = aatan(0,0,xcr,ycr) * 120000/PI;
pos_r = (long) arm_angle;
}
}
if (inside_arm) bp--;
if ( (bp == -1) && (nbp != 0) ) bp = BL - 1;
}

while( (ReadClock()-begtime) < 10 ); // 10 ms sampling time
no_sampling++;
printf("\rRobot posture: %6.2f %6.2f %6.2f %ld",Xc,Yc,Tc,no_sampling);
begtime = ReadClock();
}
RA_flag = 0;
break;

case 'b' :
    RA_flag = 0;
    break;

case 'c' :
    cet_rt(&Xc,&Yc,&Tc);
    printf("\nRobot posture: %6.2f %6.2f %6.2f\n",Xc,Yc,Tc);
    break;

case 'f' :
    relay_off(0);
    relay_off(1);
    relay_off(2);
    RA_flag = 0;
    break;

case 'h' :
    relay_off(0);
    relay_off(1);
    relay_off(2);
    RA_flag = 0;
    Stop_Motors();
    break;

case 'j' :
    RA_flag = 0;
    sendline("CALL DEMO");
    while( !kbhit() ) {
        joystick(0);
        cet_rt(&Xc,&Yc,&Tc);
        printf("\rRobot posture: %6.2f %6.2f %6.2f ",Xc,Yc,Tc);
    }
    rsout(ESC);
    break;

case 'k' :
    relay_off(0);
    relay_off(1);

```

```

        relay_on(2);
        RA_flag = 0;
        while( !kbhit() ) joystick_rear(0);
        relay_off(2);
        break;

/*
case 'l' :
    ik = Tracking_Control_Laser();
    if ( ik != 0)
        printf("\n.....Tracking crack path. Type any key to stop.");
    else
        printf("\n.....Error on tracking control with laser.");
    break;

case 'm' :
    ik = Tracking_Control_Laser_real();
    if ( ik != 0)
        printf("\n.....Tracking crack path. Type any key to stop.");
    else
        printf("\n.....Error on tracking control with laser.");
    break;

*/

case 'o' :
    relay_on(0);
    relay_on(1);
    relay_on(2);
    break;

case 'p' :
    ik = Tracking_Control();
    if ( ik != 0)
        printf("\n.....Tracking sinusoidal curve. Type any key to stop.");
    else
        printf("\n.....Error on tracking control mode.");
    break;

case 'q' :
    sendline("STOP");
    Stop_Motors();
    relay_off(0);
    relay_off(1);
    RA_flag = 1;
    begtime = ReadClock();
    pos_r = 0;
    while( ReadClock() - begtime < 2000 );
    relay_off(2);

#ifdef TMR_INTR
    restore_timer();
#endif //TMR_INTR

    exit(1);

```



```

        case 'r' :
            relay_on(2);
            RA_flag = 1;
            printf("\nEnter reference position (0 - 120000): ");
            scanf("%ld",&tmp_pos_r);
            if (tmp_pos_r < 0 || tmp_pos_r > 120000) {
                Send_Velocity_RearArm(0);
                break;
            }
            else pos_r = tmp_pos_r;
            break;

        case 's' :
            relay_on(2);
            printf("\n\nInput speeds (left, right, rear arm (RPM)): ");
            scanf("%d %d %d",&wl, &wr, &ra);
            Send_Velocity_Commands(wl,wr);
            Send_Velocity_RearArm( ra );
            break;

        case 'v' :
            _setvideomode( _DEFAULTMODE );
            break;

    };

}while(1);
}

void Help_Screen()
{
    printf("\n ? : Help screen ");
    printf("\n a : Joystick control including rear arm ");
    printf("\n b : Clear rear arm control flag ");
    printf("\n c : Read CET ");
    printf("\n f : Turn off relay ");
    printf("\n h : Halt all motors ");
    printf("\n j : Joystick control (not include rear arm) ");
    printf("\n k : Swing rear arm with joystick ");
    printf("\n l : Laser tracking control ");
    printf("\n o : Turn on relay ");
    printf("\n p : Preprogrammed path ");
    printf("\n q : Quit! ");
    printf("\n r : Set rear arm position command (0-120000 = 0-180degree) ");
    printf("\n s : Send speed commands to motor drives ");
    printf("\n v : Return to default vedio mode \n");
}

#ifdef TMR_INTR //////////////////////////////////////
void interrupt far Timer_Intr_SR(void)
/* Interrupt Service Routine */

```

```

/* This routine is interrupted whenever timer 0 overflows */
{
    int ra;
    int RA_flag_1 = 1;

    if (pos_r < 0 || pos_r > 120000) RA_flag_1 = 0;

    if (RA_flag && RA_flag_1) {

        pos_c = Read_Rear_Encoder();
        pos_e = pos_r - pos_c;
        ra = (int) (pos_e / 20);
        if (pos_e < 10000) pos_e_int = pos_e_int + pos_e;
        pos_e_int = pos_e_int / 20;
        ra = ra + pos_e_int;
        Send_Velocity_RearArm( ra );
    }

    no_ticks++;
    outp(INTCTL0, TMREOI);
}

void init_timer(void)
/* initialize timer and interrupt enable register */
{
    OldTimerVect = _dos_getvect(TIMER_VECT); /* save old vector */
    _disable();
    _dos_setvect(TIMER_VECT, Timer_Intr_SR); /* set a new vector */
    _enable();
}

void restore_timer(void)
{
    settimer(-1);
    _dos_setvect(TIMER_VECT, OldTimerVect); /* restore DOS timer vector */
}

long ReadClock() // return time in millisecond, resolution is ms
{
    return( ms * no_ticks );
}

```

/\*\*\*\*\*

#### PROCEDURE

settimer - set interrupt interval in millisecond

#### SYNOPSIS

settimer( long ms )

#### PARAMETERS

ms - interval in millisecond

#### REMARKS

Since the max interval for the IBM-PC corresponds to a max count 65535, the maximum value of ms is limited to 54.9 ms.

\*\*\*\*\*/

```
void settimer( long ms )
{
    long count;

    if ( (ms > 0L) && (ms < 55L) )
    {
        count = ((CLOCKFREQ * ms) + 500L) / 1000L;

        outp(TIMER_CTL, 0x36);    // mode 3, 16-bit binary count

        outp(TIMER, count & 0xff); // send least sig byte first,
        outp(TIMER, (count >> 8) & 0xff); // and then most sig byte
    }
    else if (ms <= 0L)    // reset to DOS clock rate
    {
        outp( TIMER_CTL, 0x36);
        outp( TIMER, 0xff);
        outp( TIMER, 0xff);
    }
    else
    {
        printf("settimer: %ld ms out of timer range\n", ms);
    }
}

#endif
```

```
void relay_on(int rn)
{
    int base,reg,bitnum, portx;
    char ch;

    base = 0x330;

    reg = rn / 8;
    if (reg == 0) bitnum = rn;
    else bitnum = rn - 8;

    if (reg == 0) {
        portx = inp(base + 4);
        portx = portx | (1 << bitnum);
        outp(base+4,portx);
    }
    else {
        portx = inp(base + 5);
        portx = portx | (1 << bitnum);
        outp(base+5,portx);
    }
}
```

```

    }
}

void relay_off(int rn)
{
    int base,reg,bitnum, portx;
    char ch;

    base = 0x330;

    reg = rn / 8;
    if (reg == 0) bitnum = rn;
    else bitnum = rn - 8;

    if (reg == 0) {
        portx = inp(base + 4);
        portx = portx & ~(1 << bitnum);
        outp(base+4,portx);
    }
    else {
        portx = inp(base + 5);
        portx = portx & ~(1 << bitnum);
        outp(base+5,portx);
    }
}

/*****
void joystick(int flag)
*****/
{
    float Volt0, Volt1, Left, Right;
    int wl, wr;

    Volt0 = AD_convert(0) - Volt0_i;
    Volt1 = AD_convert(1) - Volt1_i;
    if (fabs(Volt0) < 0.05) Volt0 = 0;
    if (fabs(Volt1) < 0.05) Volt1 = 0;

    if (Volt0 <= -0.05) movef_flag = 1; // move forward flag
    else movef_flag = 0;

    if (flag && !movef_flag) Volt0 = 0; // if flag is true, forward motion only

    Left = - Volt0 * 1500 + 1000 * Volt1;
    Right = Volt0 * 1500 + 1000 * Volt1;

    wl = (int) Left;
    wr = (int) Right;
    Send_Velocity_Commands(wl,wr);

}

/*****
void joystick_rear(int flag)
*****/

```

```

/*****/
{
    float Volt0, Volt1, Left, Right;
    int wl, wr;

    Volt0 = AD_convert(0) - Volt0_i;
    Volt1 = AD_convert(1) - Volt1_i;
    if (fabs(Volt0) < 0.05) Volt0 = 0;
    if (fabs(Volt1) < 0.05) Volt1 = 0;

    Left = Volt0 * 500;

    printf("Voltages: %5.3f %5.3f\r", Volt0, Volt1);
    if (flag) {
        Left = Left * 0.2;
        Right = Right * 0.2;
    }
    wl = (int) Left;

    Send_Velocity_RearArm(wl);

//    fprintf(outfile, "%4.2f %4.2f\n", Left, Right);
}

/*****/
float AD_convert(int ch_no)
/*****/
{
    unsigned ADC_value, MSB, LSB;
    int i;
    float Volt;

    outp(ADC_CONTROL, ch_no);
    outp(ADC_START, 0);
    for (i=0; i<10; i++); // wait for a while to avoid over-running the ADC
    while( inp(ADC_STATUS) & 0x80 );
    MSB = inp(ADC_MSB) & 0xff;
    LSB = inp(ADC_LSB) & 0xff;
    ADC_value = MSB * 16 + LSB / 16;
    Volt = ((float) ADC_value) / 409.5 - 5;
    return(Volt);
}

/*****/
void init_joystick(void)
/*****/
{
    int i;

    Volt0_i = 0;
    Volt1_i = 0;
    for (i=0; i<10; i++) {
        Volt0_i = AD_convert(0) + Volt0_i;
        Volt1_i = AD_convert(1) + Volt1_i;
    }
}

```

```

    }
    Volt0_i = Volt0_i / 10;
    Volt1_i = Volt1_i / 10;
}

/*****
/* Send velocity commands to the motor drives */
*****/
void Send_Velocity_Commands(int wl, int wr)
{
    int tmp_read;
    int chl;          /* Channel and value to write */
    int HByte, LByte; /* High byte and low byte */

    wl = -wl;
    wr = -wr;

    if (wl > S_limit) wl = S_limit;
    if (wl < -S_limit) wl = -S_limit;
    if (wr > S_limit) wr = S_limit;
    if (wr < -S_limit) wr = -S_limit;

    wl = wl / 2 + 2047; /* convert rpm to DAC number */
    wr = wr / 2 + 2047; /* 0 = -4000 rpm, 2048 = 0 rpm, 4095 = 4000 rpm */

    HByte = wl / 256; /* Convert to high byte */
    LByte = wl & 0xFF; /* Convert to low byte */
    chl = 0;
    outp(BaseAddr+chl*2,LByte); /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte); /* Write high byte second */
    HByte = wr / 256; /* Convert to high byte */
    LByte = wr & 0xFF; /* Convert to low byte */
    chl = 1;
    outp(BaseAddr+chl*2,LByte); /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte); /* Write high byte second */
}

/*****
/* Send zero velocity commands to the motor drives */
*****/
void Stop_Motors()
{
    int wl, HByte, LByte, chl;

    wl = 2047; /* convert rpm to DAC number */

    HByte = wl / 256; /* Convert to high byte */
    LByte = wl & 0xFF; /* Convert to low byte */
    chl = 0;
    outp(BaseAddr+chl*2,LByte); /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte); /* Write high byte second */
    chl = 1;
    outp(BaseAddr+chl*2,LByte); /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte); /* Write high byte second */
}

```

```

    chl = 2;
    outp(BaseAddr+chl*2,LByte);    /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);  /* Write high byte second */
}

/*****
/* Send velocity commands to the rear arm motor drives      */
*****/
void Send_Velocity_RearArm(int w)
{
    int chl;                /* Channel and value to write */
    int HByte, LByte;        /* High byte and low byte */

    w = -w;
    if (w > Sr_limit) w = Sr_limit;
    if (w < -Sr_limit) w = -Sr_limit;

    w = w / 2 + 2047; /* convert rpm to DAC number */
                    /* 0 = -4000 rpm, 2048 = 0 rpm, 4095 = 4000 rpm */

    HByte = w / 256;        /* Convert to high byte */
    LByte = w & 0xFF;        /* Convert to low byte */
    chl = 2;
    outp(BaseAddr+chl*2,LByte);    /* Write low byte first */
    outp(BaseAddr+chl*2+1,HByte);  /* Write high byte second */
}

/*****
/* Read encoder on rear-arm                                  */
*****/
long Read_Rear_Encoder()
{
    long d_cnt;

    d_cnt = read_cntr(Axis_D, enc_base);
    if (d_cnt > 8388608) d_cnt = 16777215 - d_cnt;
    else d_cnt = -d_cnt;
    return(d_cnt);
}

/*****
/* Real-time solutions for CET measurement                  */
*****/
void cet_rt(float *Xc, float *Yc, float *Tc)
{
    int i,j,k,kk;
    float xx, L1, L2,t1,t2,AA, th;

    get_CET(&L1,&L2,&th);
    // printf("\n%f %f\n",L1,L2);
    // printf("\nEnter L1 L2 :");
    // scanf("%f %f",&L1,&L2);

```

```
// printf("\n");

// check validity of data, L1,L2.
if ( (L1+L2 < DD) || (L1+DD < L2) || (L2+DD < L1) )
    printf("\nIt's not a triangle! Try again\n");
else {
    if ((DD >= L1) && (DD >= L2)) {
        AA = acos((L1*L1+L2*L2-DD*DD)/(2*L1*L2));
        t2 = asin(L1*sin(AA)/DD);
        t1 = asin(L2*sin(AA)/DD);
    }
    else if ((L1 >= DD) && (L1 >= L2)) {
        t2 = acos((DD*DD+L2*L2-L1*L1)/(2*DD*L2));
        t1 = asin(L2*sin(t2)/L1);
    }
    else {
        t1 = acos((L1*L1+DD*DD-L2*L2)/(2*L1*DD));
        t2 = asin(L1*sin(t1)/L2);
    }
}

// Initial guess
x[1] = -DD2 + L1 * cos(t1);
x[2] = L1 * sin(t1);
x[3] = t1;
x[4] = t2;

// printf("Starting initial vector \n");
// for (i=1;i<=4;i++) {
//     printf("%7s%1d%s %5.2f\n",
//         "x[",i,"] = ",x[i]);
// }
// printf("\n");
// mnewt(10,N,TOLX,TOLF,L1,L2);

// usrfun(L1,L2);
// printf("%5s %13s %13s\n","i","x[i]","f");
// for (i=1;i<=N;i++)
//     printf("%5d %14.6f %15.6f\n",i,x[i],-bet[i]);
// }

th = -th*0.00011877 - x[4] + Thr0;

*Xc = x[1];
*Yc = x[2];
*Tc = th;

}

/*****
void get_CET(float *L1, float *L2, float *th)
/*****/
{
    long a_cnt, b_cnt, c_cnt;          /* Counter values */

```



```

a_cnt = read_cntr(Axis_A, enc_base);          /* Reading counters */
b_cnt = read_cntr(Axis_B, enc_base);
c_cnt = read_cntr(Axis_C, enc_base);
// printf("\n%d %d %d\n",a_cnt,b_cnt,c_cnt);

if ( a_cnt > MaxEncoder2 ) {
    *L1 = MaxEncoder - a_cnt;
}
else {
    *L1 = - a_cnt;
}
*L1 = *L1/Sensitivity + IL1;

if ( b_cnt > MaxEncoder2 ) {
    *L2 = MaxEncoder - b_cnt;
}
else {
    *L2 = - b_cnt;
}
*L2 = *L2/Sensitivity + IL2;

if ( c_cnt > MaxEncoder2 ) {
    *th = MaxEncoder - c_cnt;
}
else {
    *th = - c_cnt;
}
}

/*****
/* User functions (non-linear simultaneous equations) to be solved */
/* CET position equations are listed below. */
*****/
void usrfun(float L1,float L2)
{
    alpha[1][1] = 0.0;
    alpha[1][2] = 1.0;
    alpha[1][3] = -L1*cos(x[3]) - rp*sin(x[3]) + rp*(PI-x[3])*cos(x[3]) + rp*sin(x[3]);
    alpha[1][4] = 0.0;
    alpha[2][1] = sin(x[3]);
    alpha[2][2] = -cos(x[3]);
    alpha[2][3] = x[2]*sin(x[3]) + (HH+x[1])*cos(x[3]);
    alpha[2][4] = 0.0;
    alpha[3][1] = 0.0;
    alpha[3][2] = 1.0;
    alpha[3][3] = 0.0;
    alpha[3][4] = -L2*cos(x[4]) - rp*sin(x[4]) + rp*(PI-x[4])*cos(x[4]) + rp*sin(x[4]);
    alpha[4][1] = -sin(x[4]);
    alpha[4][2] = -cos(x[4]);
    alpha[4][3] = 0.0;
    alpha[4][4] = x[2]*sin(x[4]) + (HH-x[1])*cos(x[4]);
    bet[1] = L1*sin(x[3]) - rp*(PI-x[3])*sin(x[3]) - x[2] + rp*cos(x[3]);
    bet[2] = x[2]*cos(x[3]) - (HH+x[1])*sin(x[3]) - rp;
}

```

```

bet[3] = L2*sin(x[4]) - rp*(PI-x[4])*sin(x[4]) - x[2] + rp*cos(x[4]);
bet[4] = x[2]*cos(x[4]) - (HH-x[1])*sin(x[4]) - rp;
}

#define TINY 1.0e-20;

void ludcmp(int n,int *indx,float *d)
{
    int i,imax,j,k;
    float big,dum,sum,temp;
    float vv[N+1];

    *d=1.0;
    for (i=1;i<=n;i++) {
        big=0.0;
        for (j=1;j<=n;j++)
            if ((temp=fabs(alpha[i][j])) > big) big=temp;
        if (big == 0.0) printf("\nSingular matrix in routine LUDCMP\n");
        vv[i]=1.0/big;
    }
    for (j=1;j<=n;j++) {
        for (i=1;i<j;i++) {
            sum=alpha[i][j];
            for (k=1;k<i;k++) sum -= alpha[i][k]*alpha[k][j];
            alpha[i][j]=sum;
        }
        big=0.0;
        for (i=j;i<=n;i++) {
            sum=alpha[i][j];
            for (k=1;k<j;k++)
                sum -= alpha[i][k]*alpha[k][j];
            alpha[i][j]=sum;
            if ( (dum=vv[i]*fabs(sum)) >= big) {
                big=dum;
                imax=i;
            }
        }
        if (j != imax) {
            for (k=1;k<=n;k++) {
                dum=alpha[imax][k];
                alpha[imax][k]=alpha[j][k];
                alpha[j][k]=dum;
            }
            *d = -(*d);
            vv[imax]=vv[j];
        }
        indx[j]=imax;
        if (alpha[j][j] == 0.0) alpha[j][j]=TINY;
        if (j != n) {
            dum=1.0/(alpha[j][j]);
            for (i=j+1;i<=n;i++) alpha[i][j] *= dum;
        }
    }
}

```

```
#undef TINY
```

```
void lubksb(int n,int *indx)
```

```
{
    int i,ii=0,ip,j;
    float sum;

    for (i=1;i<=n;i++) {
        ip=indx[i];
        sum=bet[ip];
        bet[ip]=bet[i];
        if (ii)
            for (j=ii;j<=i-1;j++) sum -= alpha[i][j]*bet[j];
        else if (sum) ii=i;
        bet[i]=sum;
    }
    for (i=n;i>=1;i--) {
        sum=bet[i];
        for (j=i+1;j<=n;j++) sum -= alpha[i][j]*bet[j];
        bet[i]=sum/alpha[i][i];
    }
}
```

```
void mnewt(int ntrial,int n,float tolx,float tolf, float L1,float L2)
```

```
{
    int k,i,indx[N+1];
    float errx,errf,d;

    for (k=1;k<=ntrial;k++) {
        usrfun(L1,L2);
        errf=0.0;
        for (i=1;i<=n;i++) errf += fabs(bet[i]);
        if (errf <= tolf) return;
        ludcmp(n,indx,&d);
        lubksb(n,indx);
        errx=0.0;
        for (i=1;i<=n;i++) {
            errx += fabs(bet[i]);
            x[i] += bet[i];
        }
        if (errx <= tolx) return;
    }
    return;
}
```

```
float aatan(float x1, float y1, float x2, float y2)
```

```
{
    float dx, dy, ang, dydx;

    dx = x2 - x1;
    dy = y2 - y1;

    if ( dx == 0 ) {
```

```

        if ( dy > 0 ) ang = PI/2;
        else if ( dy < 0 ) ang = -PI/2;
        else ang = 1000;
    }

    else if ( dx > 0 ) {
        if ( dy == 0 ) ang = 0;
        else if ( dy > 0 ) {
            dydx = dy/dx;
            if ( dydx > 100000 ) ang = PI/2;
            else ang = atan(dydx);
        }
        else {
            dydx = dy/dx;
            if ( dydx < -100000 ) ang = -PI/2;
            else ang = - atan(-dydx);
        }
    }

    else {
        if ( dy == 0 ) ang = PI;
        else if ( dy > 0 ) {
            dydx = dy/dx;
            if ( dydx < -100000 ) ang = PI/2;
            else ang = PI - atan(-dydx);
        }
        else {
            dydx = dy/dx;
            if ( dydx > 100000 ) ang = -PI/2;
            else ang = PI + atan(dydx);
        }
    }

    return(ang);
}

/*****
/* Tracking control with table reference */
/*****
int Tracking_Control(void)
{
    int wli, wri, ttt, tti;
    float th1,th2,th3, Xr,Yr,Tr, ur,rr, Xc,Yc,Tc, xa,y,p, X0,Y0,T0;
    float e = 0, c = 1.2, T2 = 24.0, R = 7.0;
    float invE[2][2], f[2], K[2][2], z, u[2], u1[2], wl, wr;
    char sf[20];
    char buffer1[100], buffer2[100];

    int j,k, xorigin, yorigin;
    int left_corner_x, left_corner_y, right_corner_x, right_corner_y;
    int x_old, x_new, y_old, y_new, x_old_r, y_old_r, x_new_r, y_new_r;
    int hor_lines, ver_lines, line_start_x, line_start_y;
    char xvalue, yvalue, thetavalue;
    float angular_pos, x_pos, y_pos;

```

```

long    begintime;

FILE    *f1;

if ( (f1 = fopen("c:\\hong\\tmr\\ncontrol\\ref_path.dat", "r")) == NULL ) {
    printf("\nError! Reference path data file can not be opened");
    return(0);
}

/* Set control gain matrix */
printf("\nInput control gains( K(1,1),K(1,2),K(2,1),K(2,2)): ");
scanf("%f %f %f %f", &K[0][0], &K[0][1], &K[1][0], &K[1][1]);

cet_rt(&X0, &Y0, &T0);
T0 = T0 + 1.5708;
_setvideomode( _VRES16COLOR );
set_workspace();

/* MAKES GRIDLINES FOR WORKSPACE */
xorigin = 9+no_vert_lines/2*xconstant;
yorigin = 65+(no_horiz_lines-2)*yconstant;
mark_origin(xorigin, yorigin);
/* SCANS FIRST POSTURE OF TMR */
x_old = xorigin+(int)(X0*xconstant/12);
y_old = yorigin-(int)(Y0*yconstant/12);

fscanf(f1, "%f %f %f %f %f\n", &Xr, &Yr, &Tr, &ur, &rr);
Yr = Yr + 30;
x_old_r = xorigin+(int)(Xr*xconstant/12);
y_old_r = yorigin-(int)(Yr*yconstant/12);

begintime = ReadClock();

while( !kbhit() && ((fscanf(f1, "%f %f %f %f %f\n", &Xr, &Yr, &Tr, &ur, &rr)) != EOF) ) {
    cet_rt(&Xc, &Yc, &Tc);
    Yr = Yr + 30;
    Tc = Tc + 1.5708;
    /* Calculate error posture in body coordinate */
    xa = (Xr - Xc)*cos(Tc) + (Yr - Yc)*sin(Tc);
    y = -(Xr - Xc)*sin(Tc) + (Yr - Yc)*cos(Tc);
    p = Tr - Tc;
    invE[0][0] = -1;
    invE[0][1] = -y/(e+xa+c);
    invE[1][0] = 0;
    invE[1][1] = -1/(e+xa+c);
    f[0] = ur*cos(p);
    f[1] = ur*sin(p) + c*rr;

    z = y + c*p;
    u1[0] = -f[0] - K[0][0] * xa - K[0][1] * z;
    u1[1] = -f[1] - K[1][0] * xa - K[1][1] * z;
    u[0] = invE[0][0] * u1[0] + invE[0][1] * u1[1];
    u[1] = invE[1][0] * u1[0] + invE[1][1] * u1[1];
    wl = ( u[0] - T2*u[1] ) / R * 9.55;
    wr = ( u[0] + T2*u[1] ) / R * 9.55;
}

```

```

wli = (int)wl; wri = (int)wr; wri = -wri;

Send_Velocity_Commands(wli,wri);

x_new = xorigin+(int)(Xc*xconstant/12);
y_new = yorigin-(int)(Yc*yconstant/12);
x_new_r = xorigin+(int)(Xr*xconstant/12);
y_new_r = yorigin-(int)(Yr*yconstant/12);

/* DISPLAYS X AND Y COORDINATES AND THETA */
_settextcolor(white);
_settextposition(3,10);
sprintf(buffer2,"x: %f in  y: %f in  theta: %f degrees", Xc, Yc, Tc*180/pi);
_outtext(buffer2);

/* DRAWS REFERENCE PATH */
_setcolor(green);
_moveto(x_old_r, y_old_r);
_lineto(x_new_r, y_new_r);

/* DRAWS TMR PATH */
_setcolor(1t_magenta);
_moveto(x_old, y_old);
_lineto(x_new, y_new);

x_old = x_new;
y_old = y_new;

x_old_r = x_new_r;
y_old_r = y_new_r;

// printf("\rRobot posture: %6.2f %6.2f %6.2f",Xc,Yc,Tc);
// while( ReadClock() - begtime < 20 );
// begtime = ReadClock();
// fprintf(ft,"%lf %lf %lf %lf %lf %lf %lf %lf %lf %lf %lf\n",Xr,Yr,Tr,Xc,Yc,Tc,x,y,p,u[0],u[1]);
// fprintf(ft2,"%lf\n",tused);

}

wli = 0; wri = 0;
Send_Velocity_Commands(wli,wri);
// fclose(ft);
fclose(f1);
_setvideomode( _DEFAULTMODE );
return(1);

}

void set_workspace(void)
{
_setbkcolor( _BLACK);
_clearscreen(_GCLEARSCREEN);

```

```

        _settextcolor(white);
        _settextposition(1,30);
        _outtext ("WORKSPACE OF TMR");
        create_replace_grid();
    }

    /* MARKS ORIGIN */
    void mark_origin(int xorigin, int yorigin)
    {
        xorigin = 9+no_vert_lines/2*xconstant;
        yorigin = 65+(no_horiz_lines-2)*yconstant;
        _setcolor(white);
        _setlinestyle(solid);
        _moveto(xorigin-xconstant, yorigin);
        _lineto(xorigin+xconstant, yorigin);
        _moveto( xorigin,yorigin-yconstant);
        _lineto( xorigin,yorigin+yconstant);
    }

    /* REPLACES PARITALLY LOST GRID AND ORIGIN MARKER */
    void create_replace_grid(void)
    {
        int i;
        _setcolor(cyan);
        _rectangle(_GBORDER, 9, 65, 639, 450);
        _settextcolor(white);
        _settextposition(13,0);
        _outtext ("60\n\n\n\n\n\n\n\n\n\n\n0");
        _settextposition(30,18);
        _outtext ("-60          0          60");

        /* HORIZONTAL LINES */
        for(i = 1; i< no_horiz_lines; i++)
        {
            _setcolor(red);
            _setlinestyle(dashed);
            _moveto(9, 65+i*yconstant);
            _lineto (639, 65+i*yconstant);
        }

        /* VERITICAL LINES */
        for(i = 1; i< no_vert_lines; i++)
        {
            _setcolor(red);
            _setlinestyle(dashed);
            _moveto(9+i*xconstant, 65);
            _lineto (9+i*xconstant, 450);
        }

        /* DRAWS HALF-CIRCLE */
        _setcolor(yellow);
        _arc(79,135,569,625,569,380,79,380);
    }

    void draw_tmr(float x, float y, float angular_pos, int xorigin, int yorigin, int x_old, int x_new, int y_old, int y_new)

```

```

{
    int i, j;
    extern int x_pos, y_pos, x0, x1, x2, x3, x4, yy0, yy1, y2, y3, y4;
    extern int tx1, tx2, tx3, tx4, tx5, tx6, tx7, tx8;
    extern int ty1, ty2, ty3, ty4, ty5, ty6, ty7, ty8;
    float tmrlength, tmrwidth, halflength, halfwidth, tirelength, tirewidth;
    char buffer1[100], buffer2[100];

    tmrlength = 30.0/12;
    tmrwidth = 20.0/12;
    halfwidth = tmrwidth/2;
    halflength = tmrlength/2;
    tirelength = 10.5/12;
    tirewidth = 3.5/12;

    /* REDRAWS THE TMR IN BLACK TO HIDE IT */
    _setcolor(black);
    _moveto(x1, yy1);
    _lineto(x2, y2);
    _lineto(x3, y3);
    _lineto(x4, y4);
    _lineto(x1, yy1);
    _moveto(tx1, ty1);
    _lineto(tx2, ty2);
    _lineto(tx3, ty3);
    _lineto(tx4, ty4);
    _lineto(tx1, ty1);
    _moveto(tx5, ty5);
    _lineto(tx6, ty6);
    _lineto(tx7, ty7);
    _lineto(tx8, ty8);
    _lineto(tx5, ty5);
    _ellipse(_GBORDER, (int)(x_pos-4), (int)(y_pos+4), (int)(x_pos+4), (int)(y_pos-4));

    x_pos = xorigin+(int)(x/12*xconstant);
    y_pos = yorigin-(int)(y/12*yconstant);

    /* DISPLAYS X AND Y COORDINATES AND THETA */
    _settextcolor(white);
    _settextposition(3,10);
    sprintf(buffer2, "x: %lf in y: %lf in theta: %lf degrees", x, y, angular_pos*180/pi);
    _outtext(buffer2);

    /* CALCULATES THE CORNER COORDINATES OF THE TMR */
    x0 = (int)(x_pos + xconstant*cga*cos(angular_pos));
    yy0 = (int)(y_pos - yconstant*cga*sin(angular_pos));
    x1 = (int)(x0 + xconstant*halfwidth*sin(angular_pos));
    yy1 = (int)(yy0 + yconstant*halfwidth*cos(angular_pos));
    x2 = (int)(x1 - xconstant*tmrlength*cos(angular_pos));
    y2 = (int)(yy1 + yconstant*tmrlength*sin(angular_pos));
    x3 = (int)(x2 - xconstant*tmrwidth*sin(angular_pos));
    y3 = (int)(y2 - yconstant*tmrwidth*cos(angular_pos));
    x4 = (int)(x1 - xconstant*tmrwidth*sin(angular_pos));
    y4 = (int)(yy1 - yconstant*tmrwidth*cos(angular_pos));

```



```

/* CALCULATES THE TMR'S TIRE COORDINATES */
tx1 = (int)(x3 - 5*sin(angular_pos));
ty1 = (int)(y3 - 5*cos(angular_pos));
tx2 = (int)(tx1 - xconstant*tirewidth*sin(angular_pos));
ty2 = (int)(ty1 - yconstant*tirewidth*cos(angular_pos));
tx3 = (int)(tx2 + xconstant*tirelength*cos(angular_pos));
ty3 = (int)(ty2 - yconstant*tirelength*sin(angular_pos));
tx4 = (int)(tx1 + xconstant*tirelength*cos(angular_pos));
ty4 = (int)(ty1 - yconstant*tirelength*sin(angular_pos));
tx5 = (int)(x2 + 5*sin(angular_pos));
ty5 = (int)(y2 + 5*cos(angular_pos));
tx6 = (int)(tx5 + xconstant*tirewidth*sin(angular_pos));
ty6 = (int)(ty5 + yconstant*tirewidth*cos(angular_pos));
tx7 = (int)(tx6 + xconstant*tirelength*cos(angular_pos));
ty7 = (int)(ty6 - yconstant*tirelength*sin(angular_pos));
tx8 = (int)(tx5 + xconstant*tirelength*cos(angular_pos));
ty8 = (int)(ty5 - yconstant*tirelength*sin(angular_pos));

/* DRAWS TMR */
_setcolor(lt_blue);
_moveto(x1, y1);
_lineto(x2, y2);
_lineto(x3, y3);
_lineto(x4, y4);
_lineto(x1, y1);
// _setcolor(blue);
_moveto(tx1, ty1);
_lineto(tx2, ty2);
_lineto(tx3, ty3);
_lineto(tx4, ty4);
_lineto(tx1, ty1);
_moveto(tx5, ty5);
_lineto(tx6, ty6);
_lineto(tx7, ty7);
_lineto(tx8, ty8);
_lineto(tx5, ty5);
_setcolor(green);
_ellipse(_GBORDER, (int)(x_pos-4), (int)(y_pos+4), (int)(x_pos+4), (int)(y_pos-4));
gcvt(x, 7, buffer1); /* gcvt converts a double to a string */
gcvt(y, 7, buffer1);
gcvt(angular_pos, 7, buffer1);

/* DRAWS TMR PATH */
_setcolor(lt_magenta);
_moveto(x_old, y_old);
_lineto(x_new, y_new);

/* ADDING TO DISPLAY TIME */
/* for(i = 0; i<20000; i++)
{
    for(j = 0; j<25; j++);
} */

/* REPLACES THE ENTIRE GRID AND ORIGIN */

```

---

```
        create_replace_grid();
        mark_origin(xorigin, yorigin);
    }

void sound_on(unsigned freq)
{
    unsigned status, ratio, part_ratio;

    status = inp(OUT_8255);
    outp(TIMER_MODE, TIMER_OSC);
    ratio = (unsigned)(TIMER_FREQ/freq);
    part_ratio = ratio & 0xff;
    outp(TIMER_COUNT, part_ratio);
    part_ratio = (ratio >> 8) & 0xff;
    outp(TIMER_COUNT, part_ratio);
    outp(OUT_8255, (status | SPKRON));
}

void sound_off(void)
{
    unsigned status;
    status = inp(OUT_8255);
    outp(OUT_8255, (status & ~SPKRON));
}
```

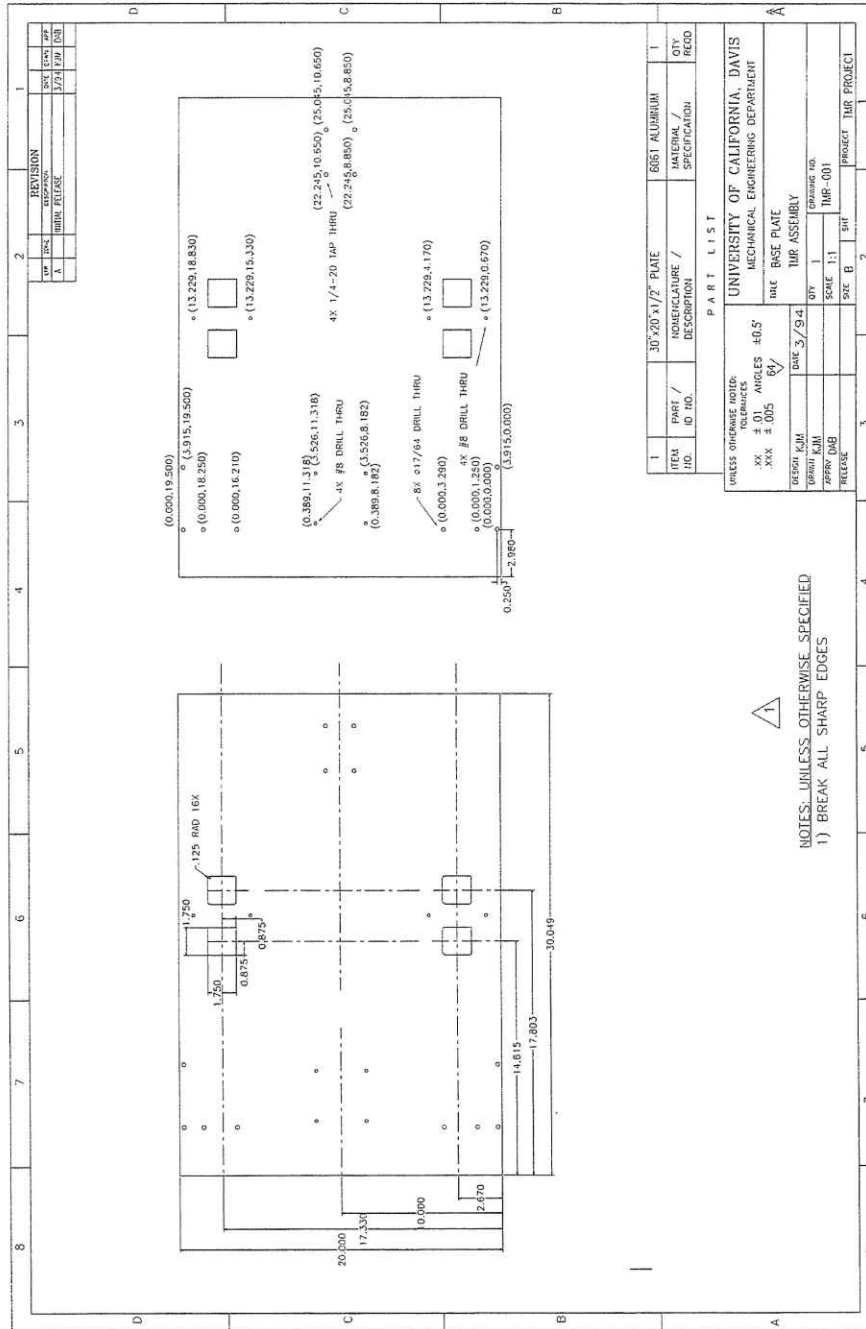
## APPENDIX C

### TECHNICAL DRAWINGS

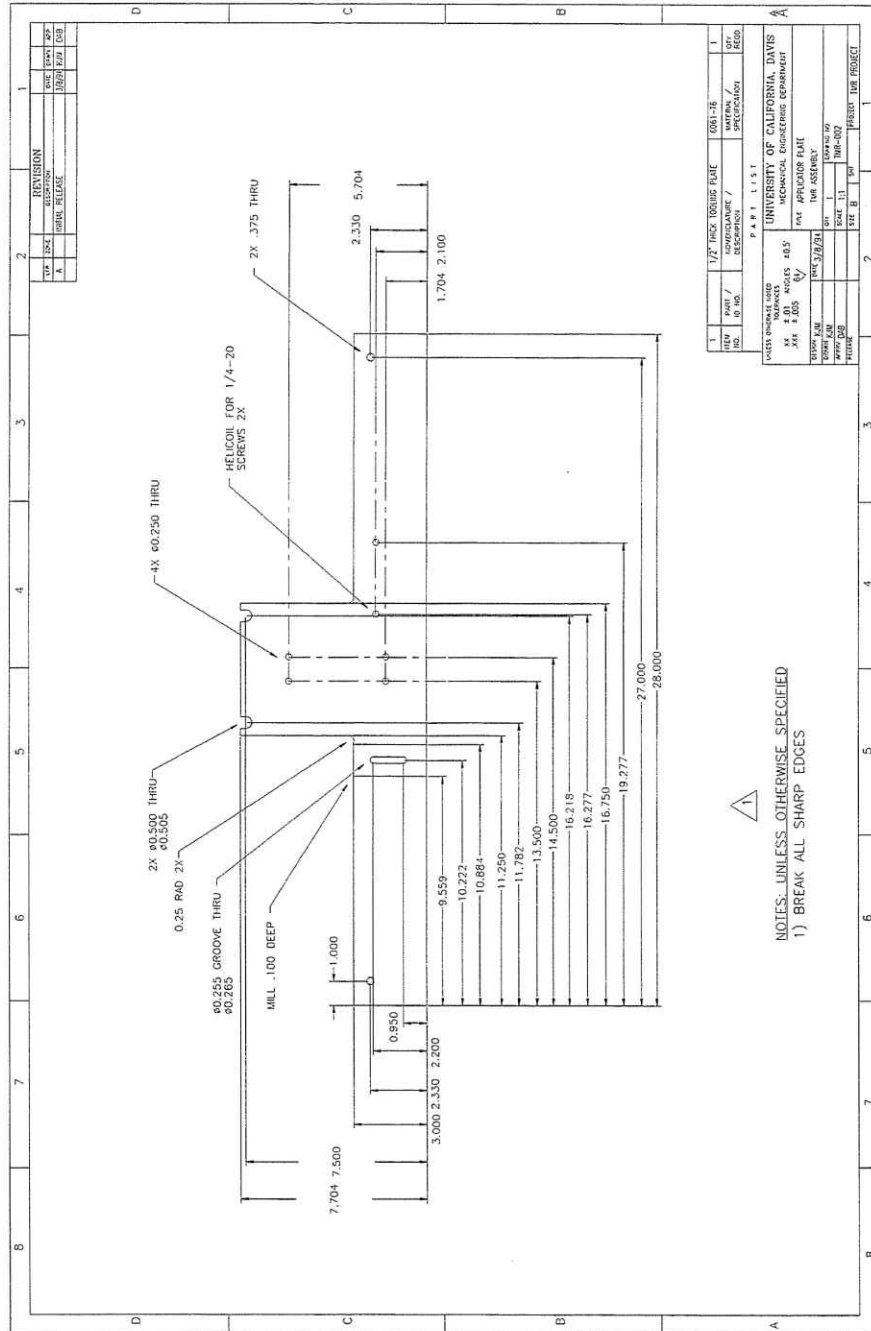
| <b><u>Drawing #</u></b> | <b><u>Title</u></b>                    |
|-------------------------|----------------------------------------|
| TMR-001                 | Base Plate                             |
| TMR-002                 | Applicator Plate                       |
| TMR-003                 | Linear Transducer Base Mount           |
| TMR-004                 | Set Off Block                          |
| TMR-005                 | Pulley                                 |
| TMR-006                 | Pulley Standoffs                       |
| TMR-007                 | Rotation Assembly                      |
| TMR-008                 | Line Connection                        |
| TMR-009                 | Rotary Components                      |
| TMR-010                 | Encoder Platform                       |
| TMR-011                 | Extra Components                       |
| TMR-012                 | Gearbox Adapters                       |
| TMR-100                 | Arm Assembly                           |
| TMR-101                 | Arm Base Mount                         |
| TMR-102                 | Vari Plate                             |
| TMR-103                 | Height Adjusting Rod/Joint Rods        |
| TMR-104                 | Bearing Capture Versions               |
| TMR-105                 | Arm Tubes                              |
| TMR-106                 | Outside Pipe                           |
| TMR-201                 | Welded Frame With Gearbox Holes        |
| TMR-201A                | Welded Frame With Extender Holes       |
| TMR-202                 | Frame Components                       |
| TMR-203                 | Index Plate                            |
| TMR-204A                | Air Spring Supports - Frame            |
| TMR-204B                | Air Spring Supports - Router Box       |
| TMR-205                 | Drive Shaft                            |
| TMR-206                 | Bearing Capture                        |
| TMR-207                 | Air Spring Supports - Router Box Angle |
| TMR-208                 | Front Wheel Supports                   |
| TMR-209                 | Welded Extender Frame                  |
| TMR-210                 | Air Spring Supports - Frame Angle      |
| TMR-211                 | C-channel Hoops on Router Frame        |
| TMR-300                 | Router Inner Case                      |
| TMR-301                 | Router Inner Case - Back Plate         |
| TMR-302                 | Router Inner Case - Front Wall         |
| TMR-303                 | Router Inner Case - Side Walls         |
| TMR-304                 | Caster Plates and Support Triangles    |
| TMR-401                 | Base Plate for Large CETS              |
| TMR-402                 | Set Off Block                          |
| TMR-403                 | Pulley                                 |

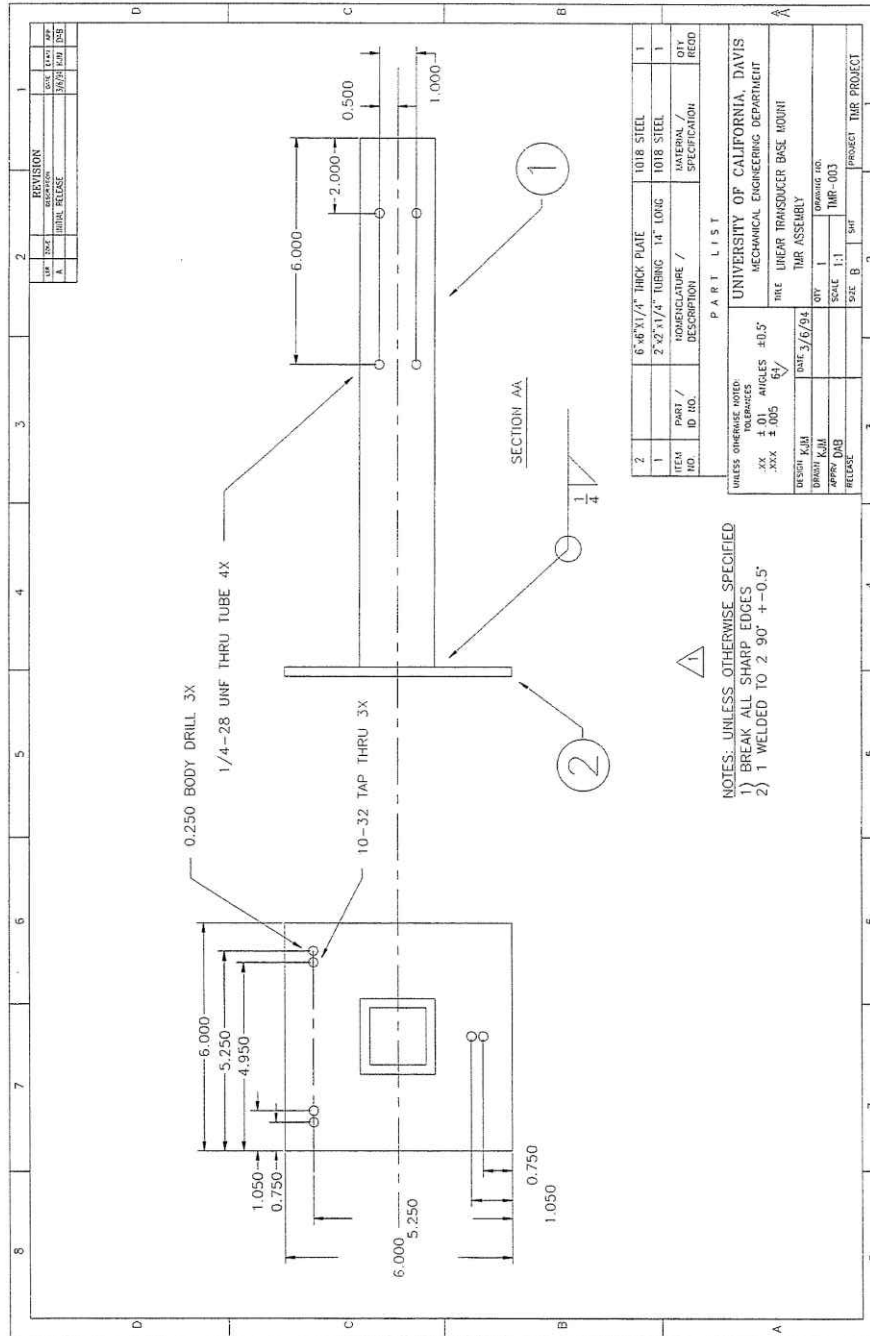
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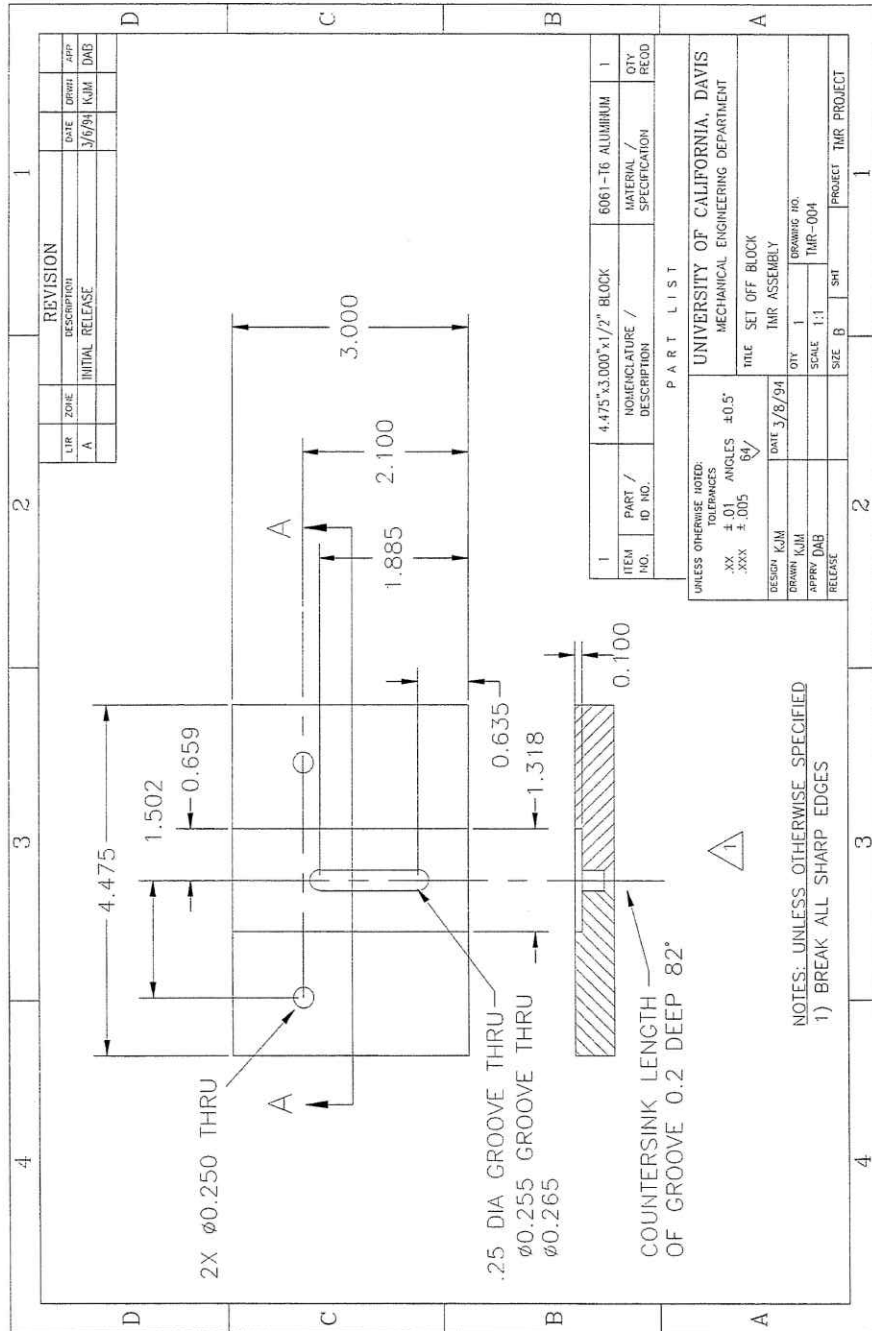
|         |                                 |
|---------|---------------------------------|
| TMR-404 | Pulley Standoffs                |
| TMR-405 | Line Connections                |
| TMR-406 | Rotary Components               |
| TMR-407 | Encoder Platform                |
| TMR-501 | Applicator Mount                |
| TMR-502 | 4-Bar Links                     |
| TMR-503 | Rotating Attachment             |
| TMR-504 | Keyway Attachment               |
| TMR-505 | Motor Seat                      |
| TMR-601 | Support for TMRR                |
| TMR-602 | Support Brackets                |
| TMR-603 | Support Bar                     |
| TMR-604 | Support Bar: Rear               |
| TMR-605 | Stop Block                      |
| TMR-606 | Chain Brackets                  |
| TMR-607 | Plates - Lift Gate              |
| TMR-608 | C-Channel: Lift Gate            |
| TMR-609 | Base: Lift Gate                 |
| TMR-610 | Gusset: Lift Gate               |
| TMR-611 | Slide Block for ACSM Truck      |
| TMR-612 | Slide Plates for ACSM Truck     |
| TMR-701 | Laser Sensor Cover              |
| TMR-702 | TMRR CET Mount Pulley Assembly  |
| TMR-703 | TMRR CET Mount Guide Assembly   |
| TMR-704 | TMRR CET Mount Right Face Plate |
| TMR-705 | TMRR CET Mount Left Face Plate  |
| TMR-706 | TMRR CET Mount Base Plate       |
| TMR-707 | TMRR CET Mount Right Back Plate |
| TMR-708 | TMRR CET Mount Left BackPlate   |
| TMR-709 | TMRR Laser Cover Mounting Plate |
| TMR-800 | Indexing Tool                   |
| TMR-900 | Booth                           |
| TMR-901 | LEXAN Retatining Strips         |
| TMR-902 | Hexagon Die                     |



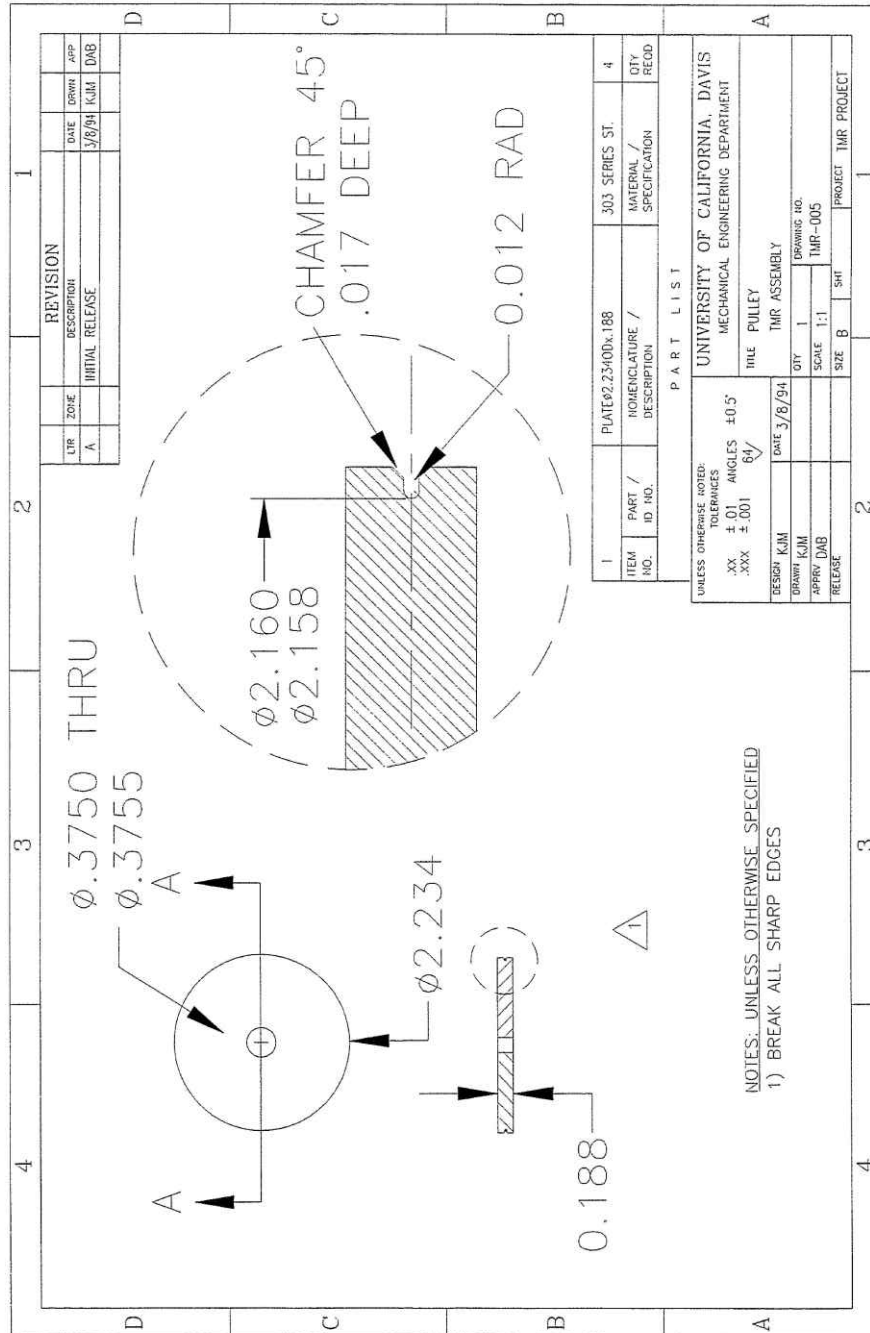
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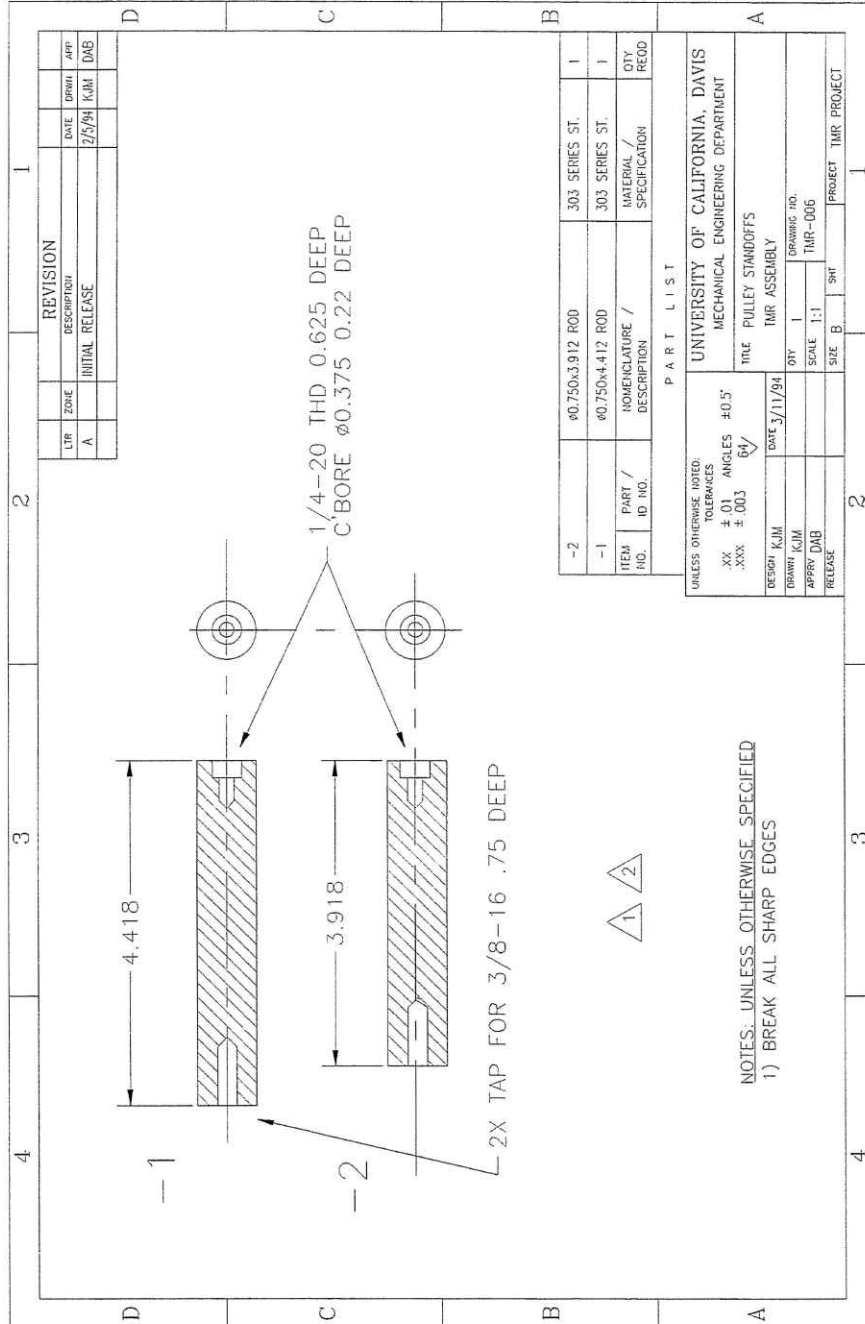






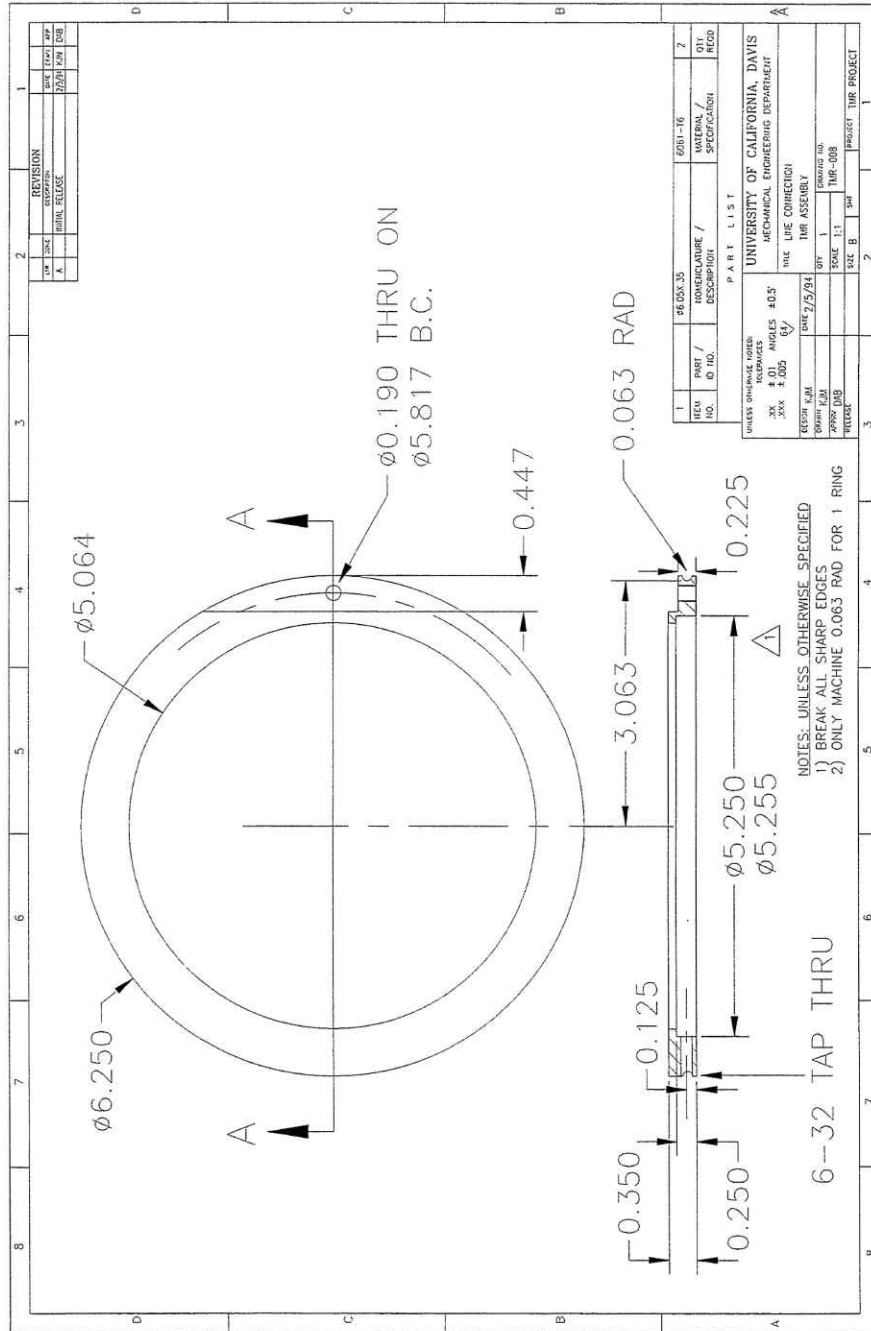




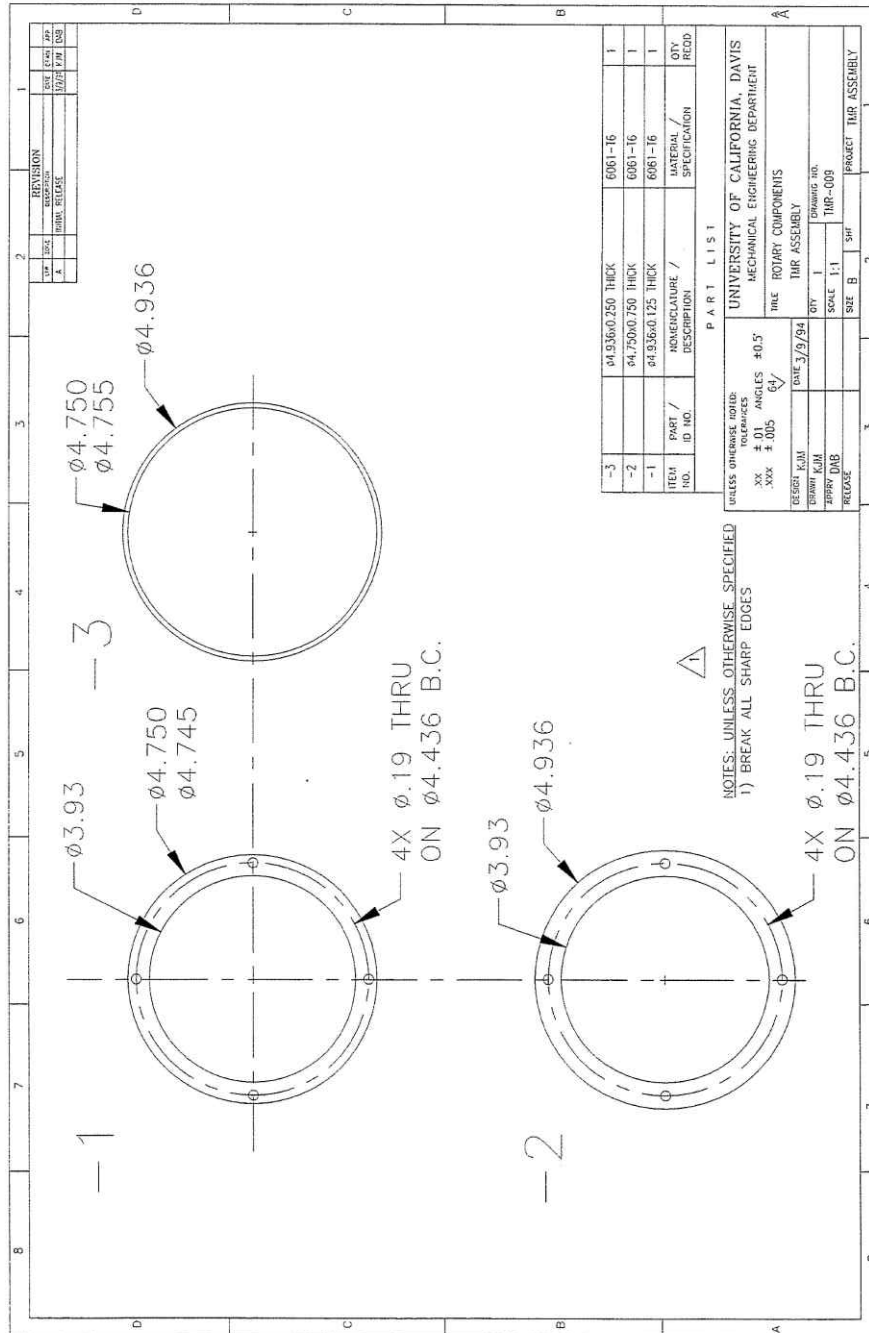


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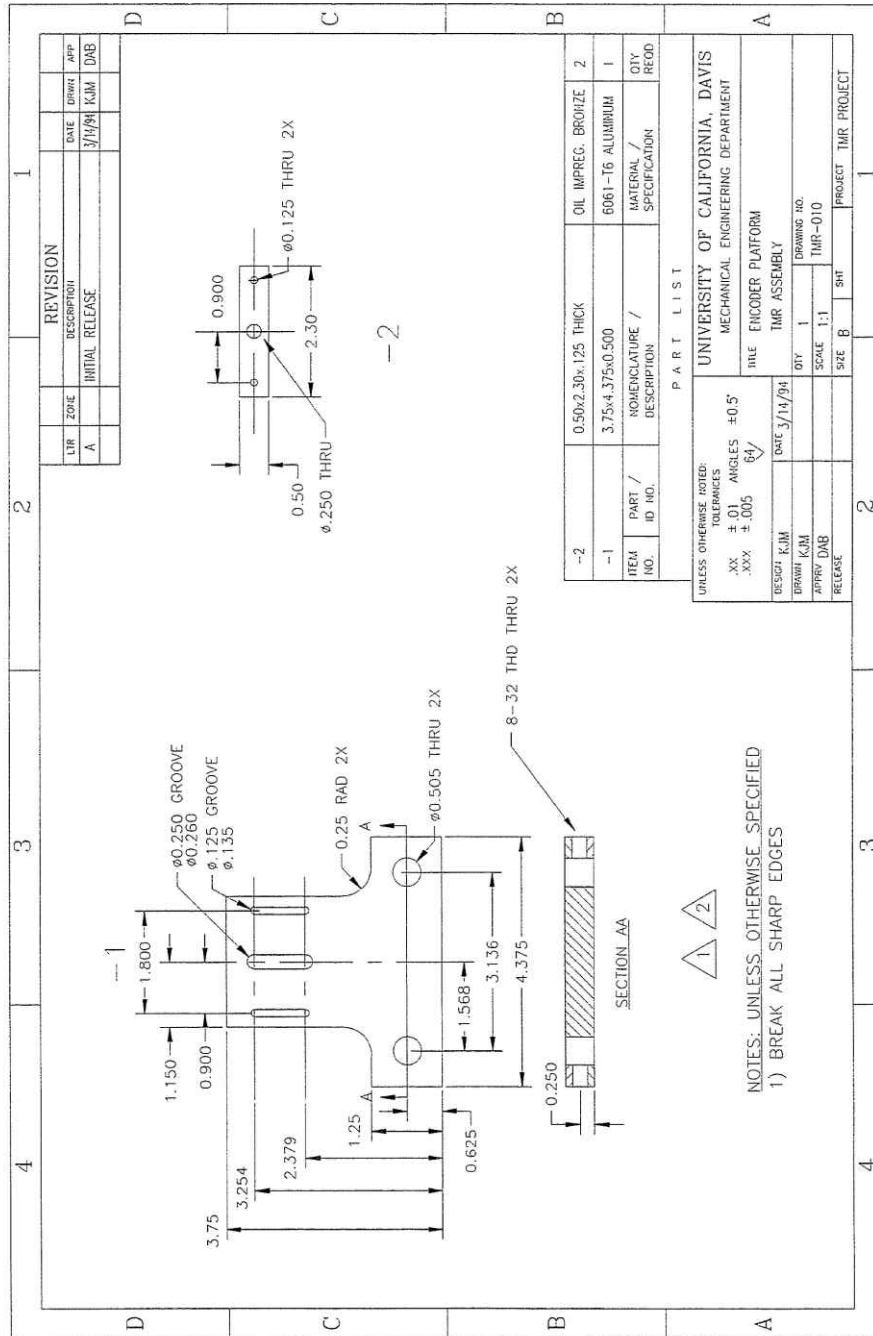




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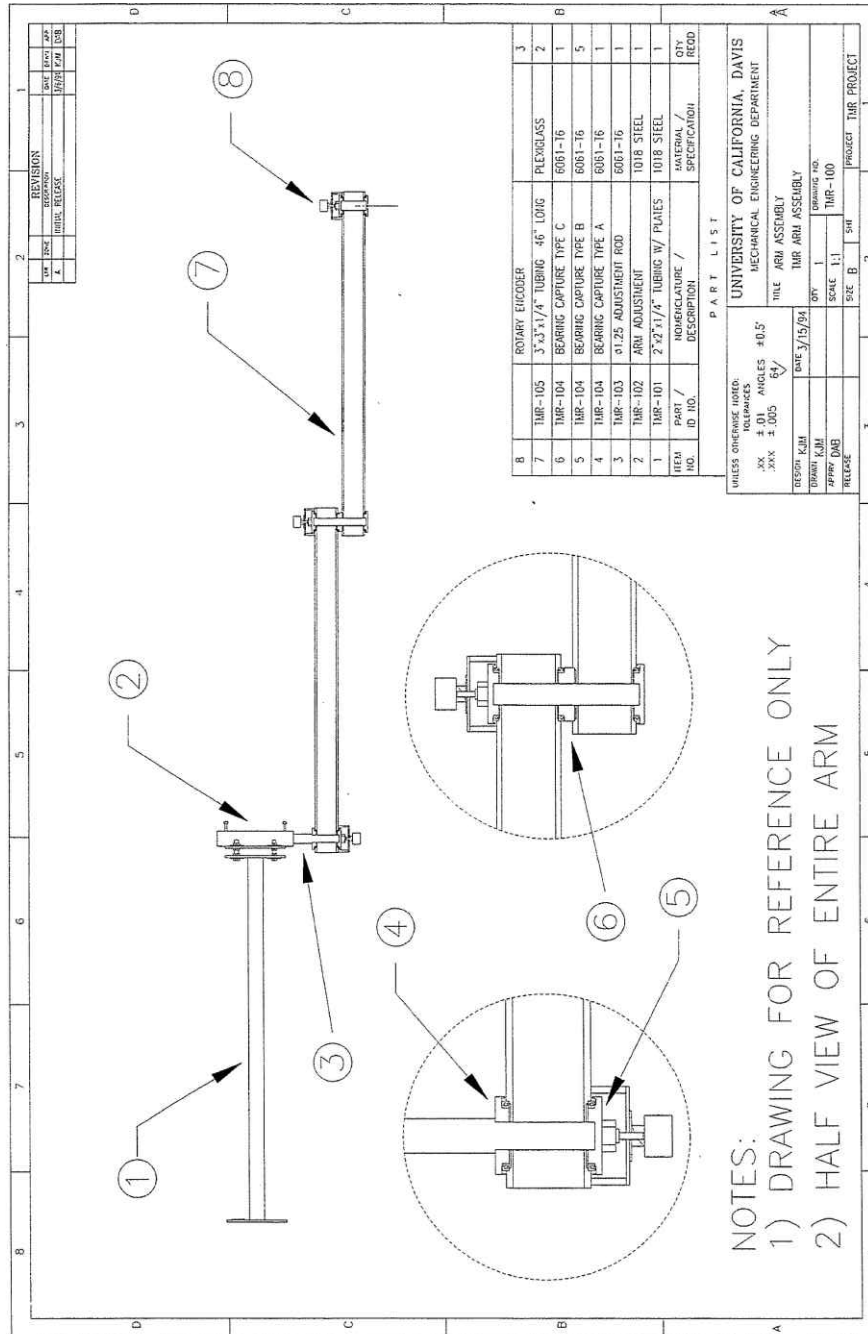


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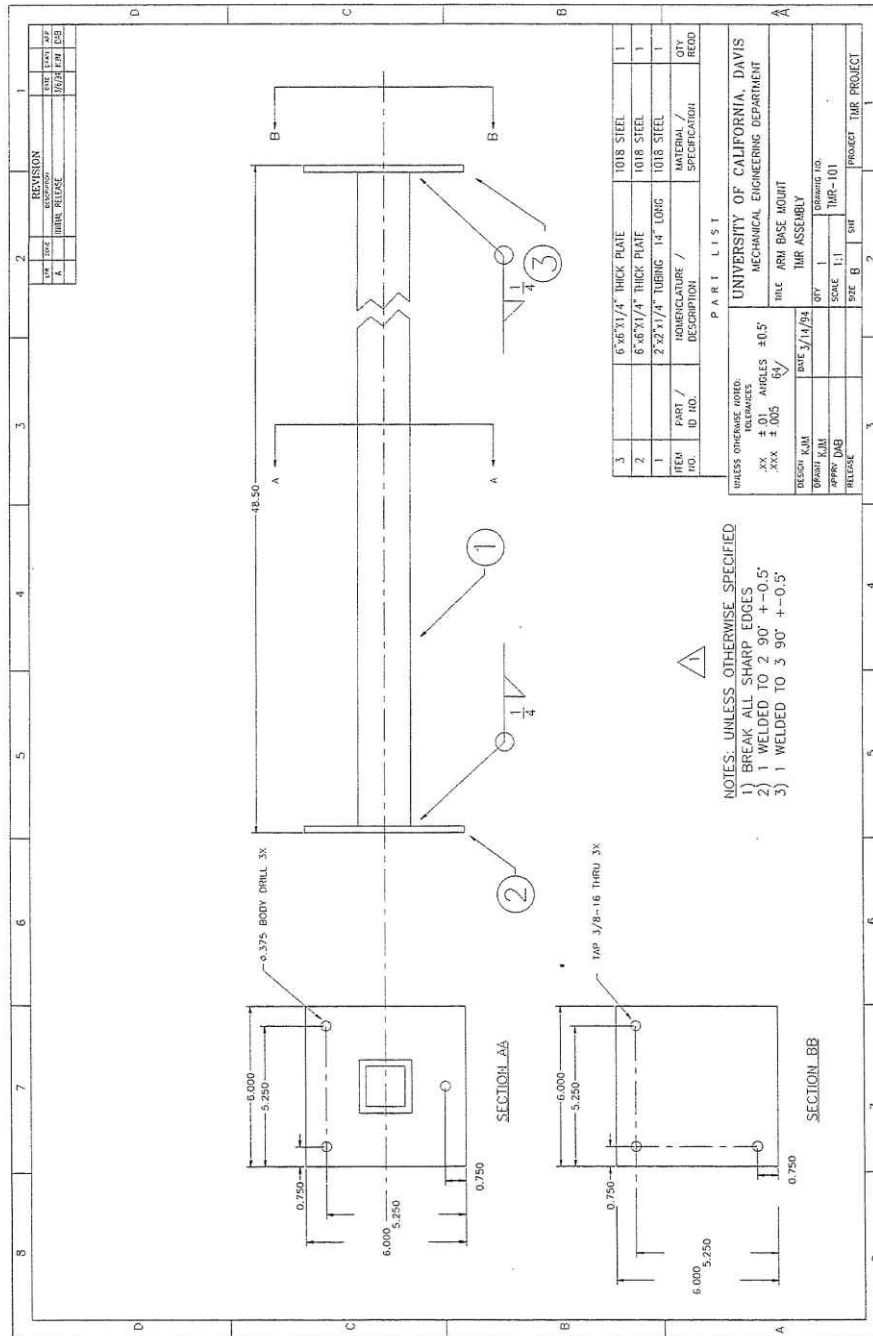






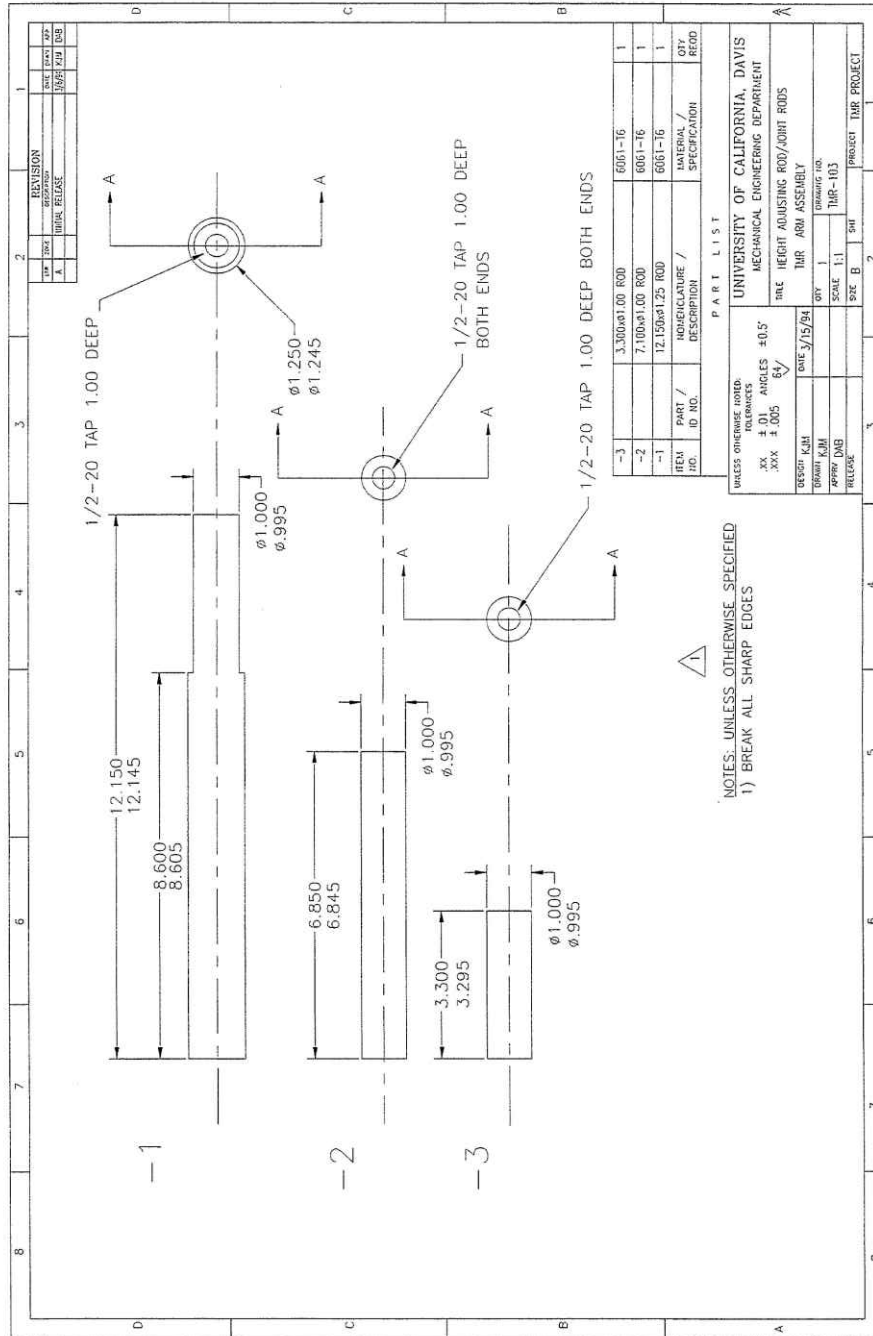


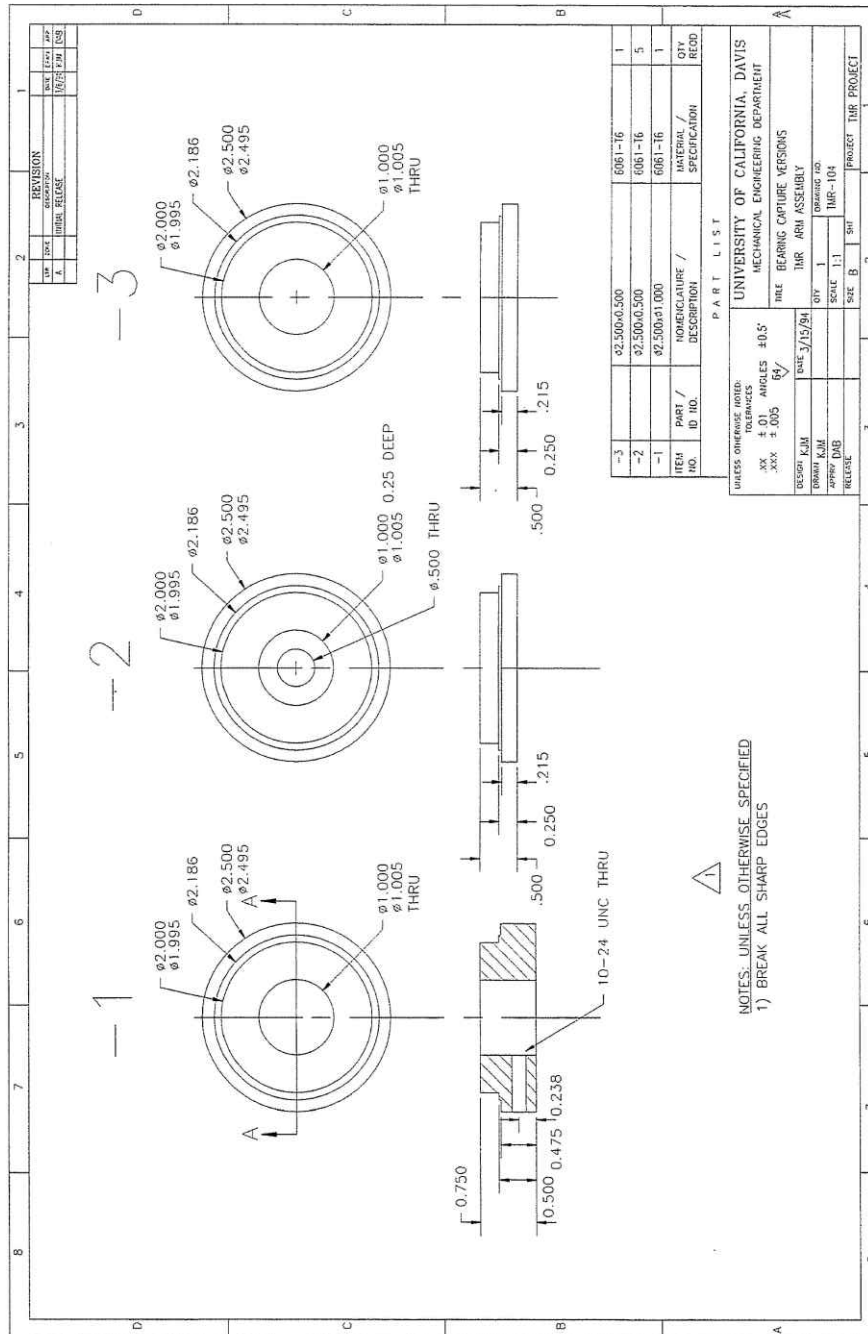
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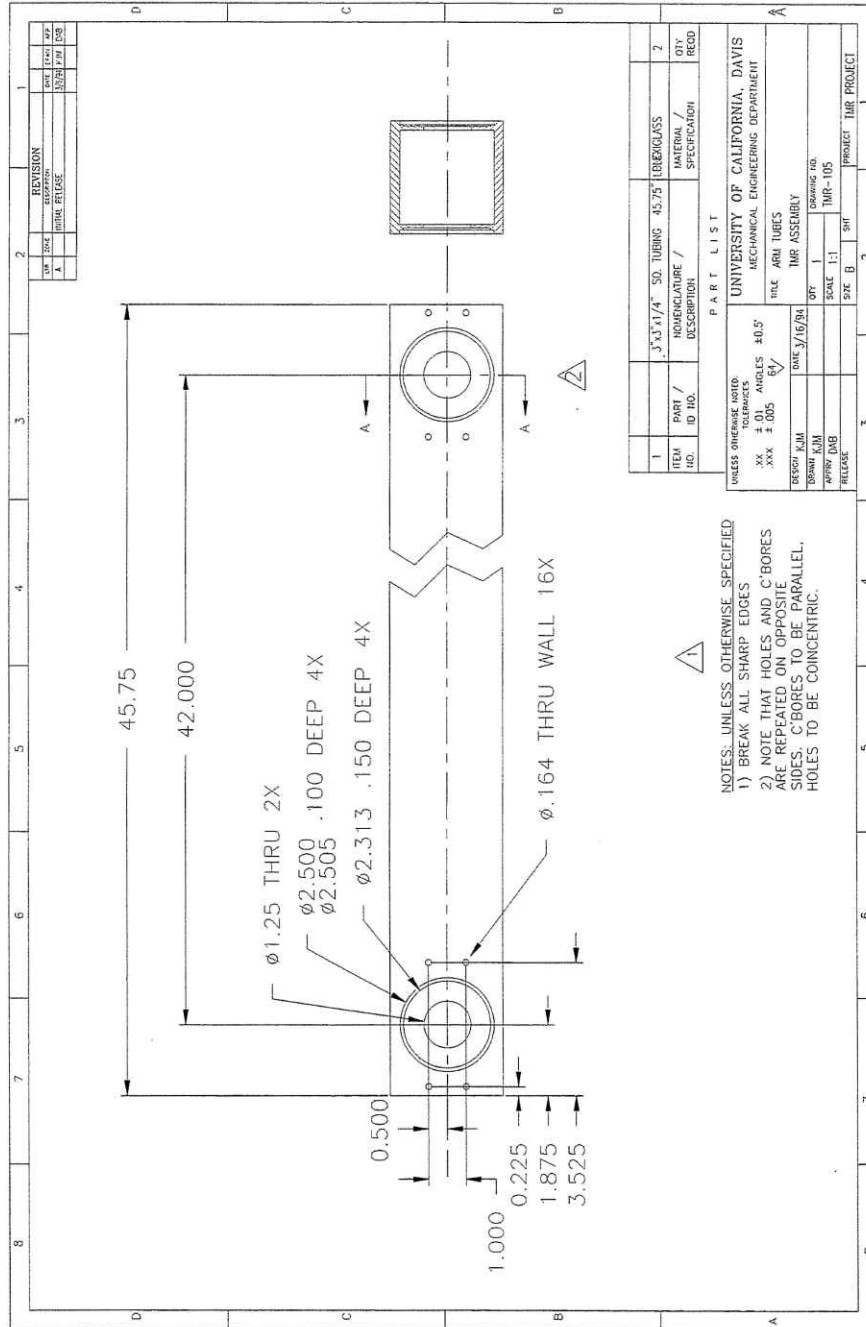
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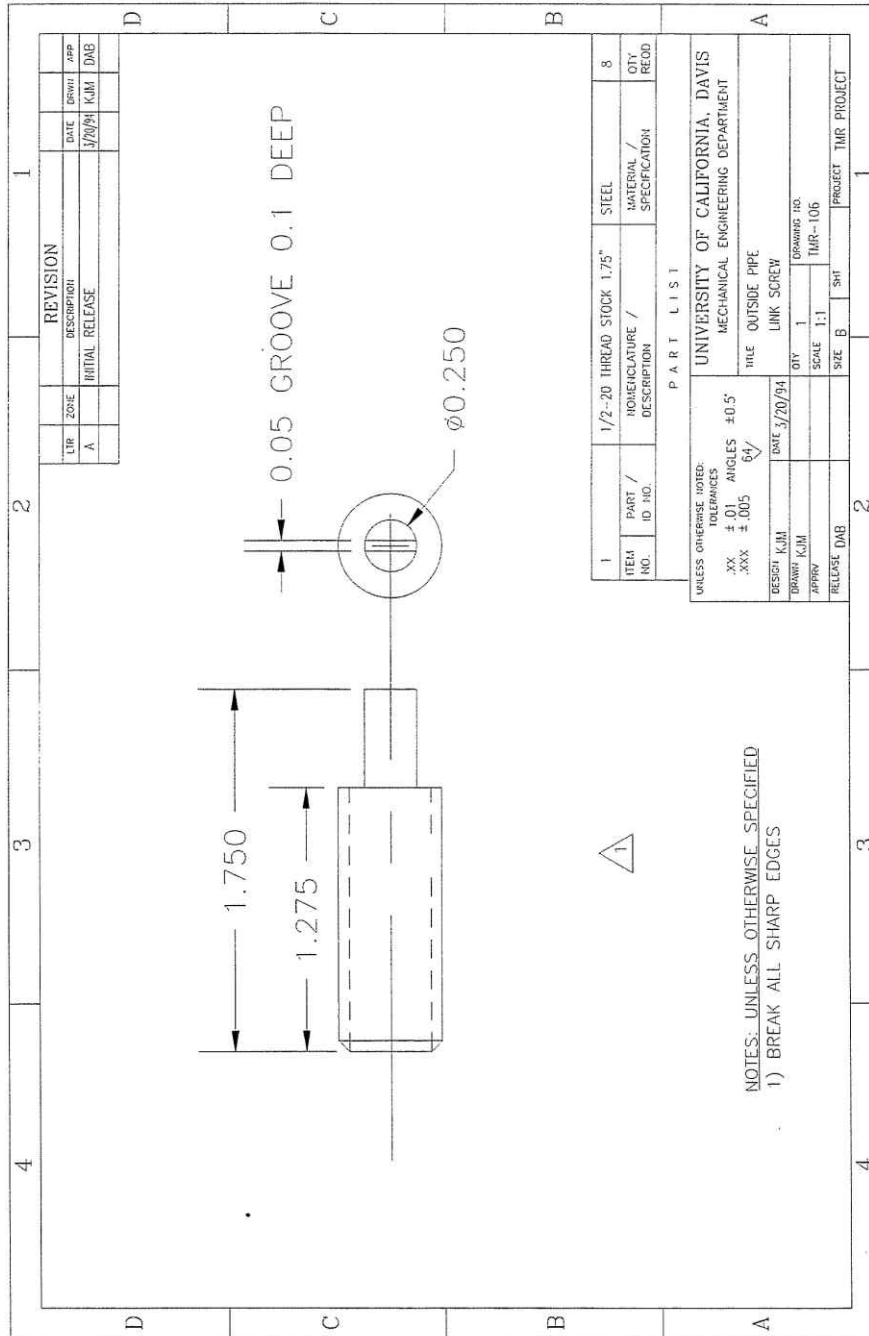


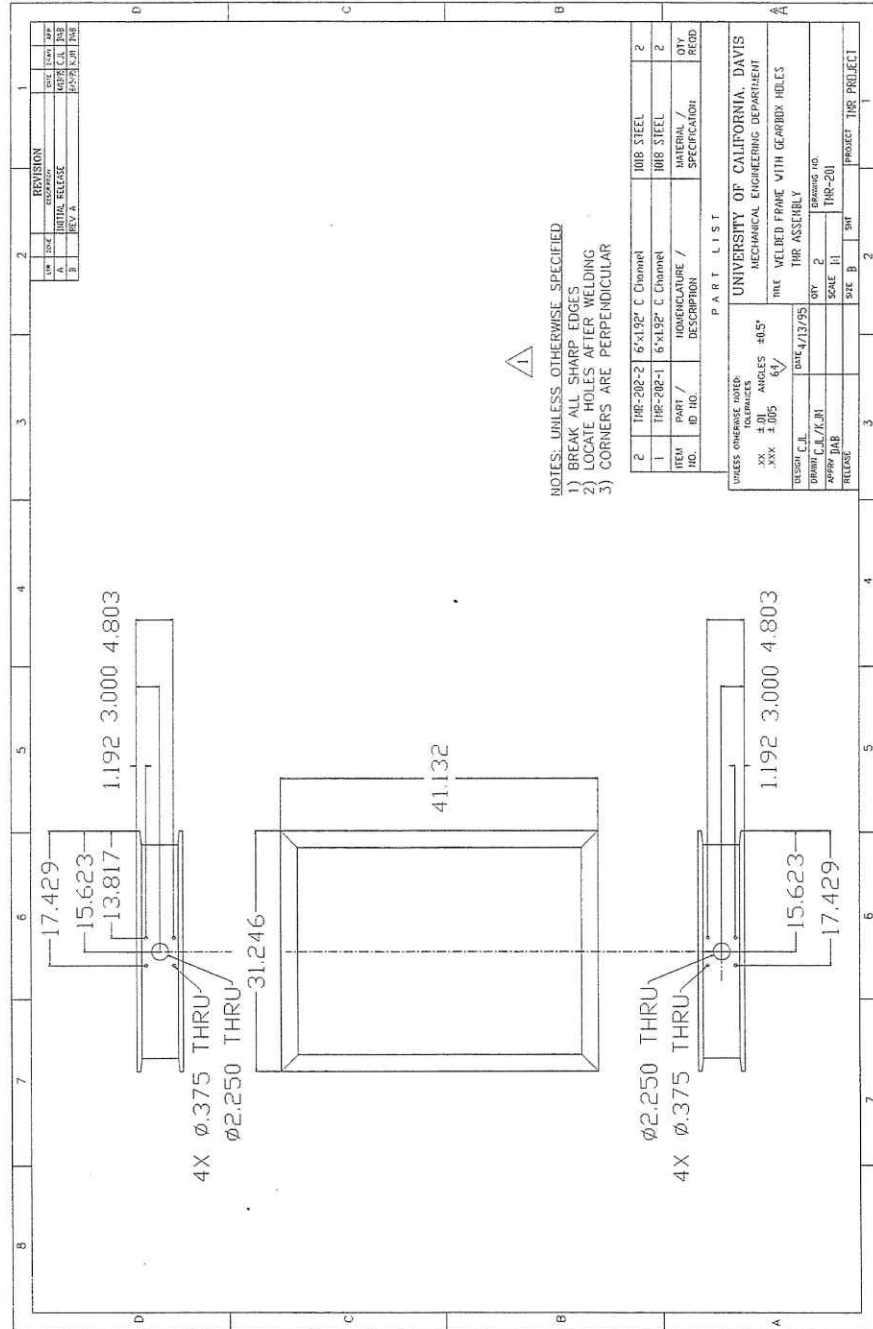


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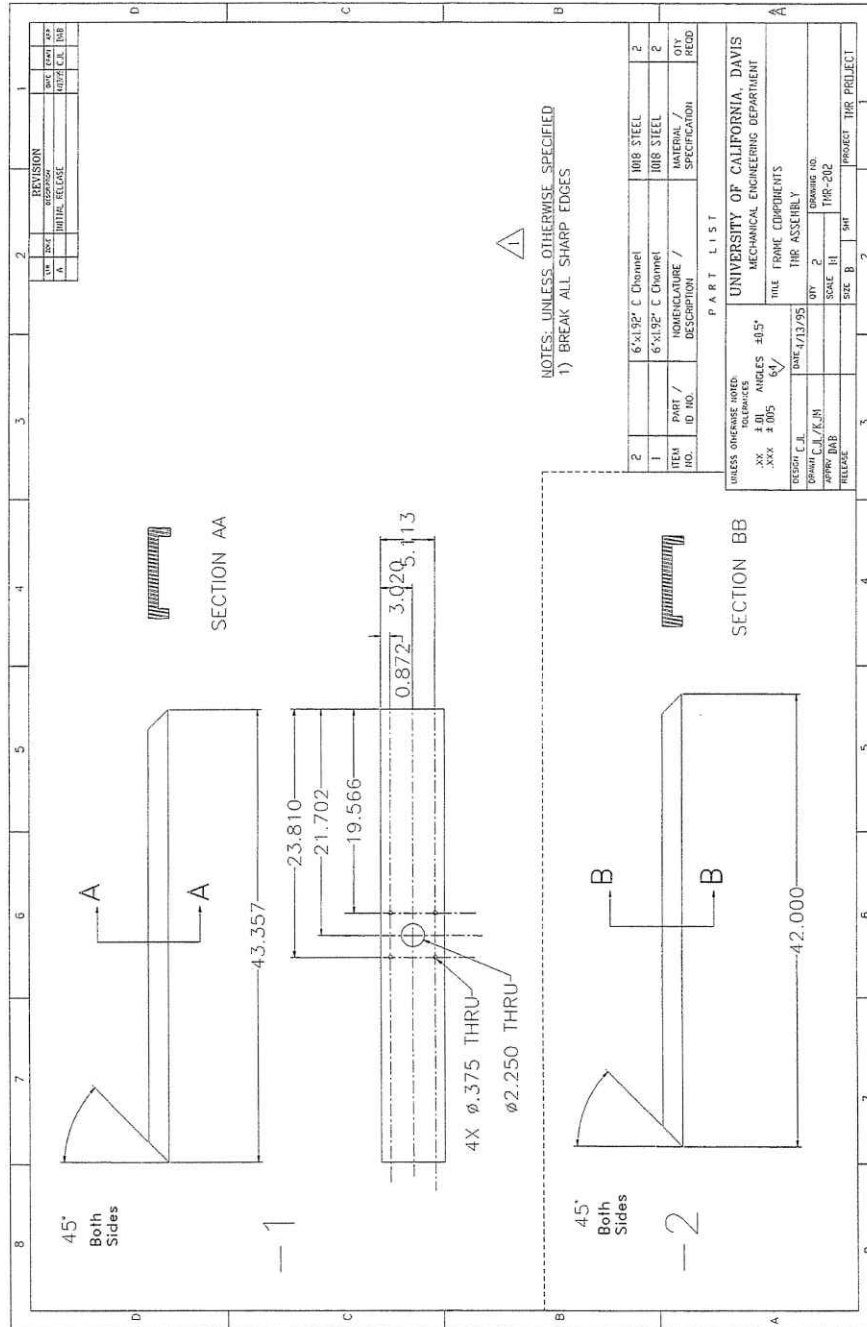


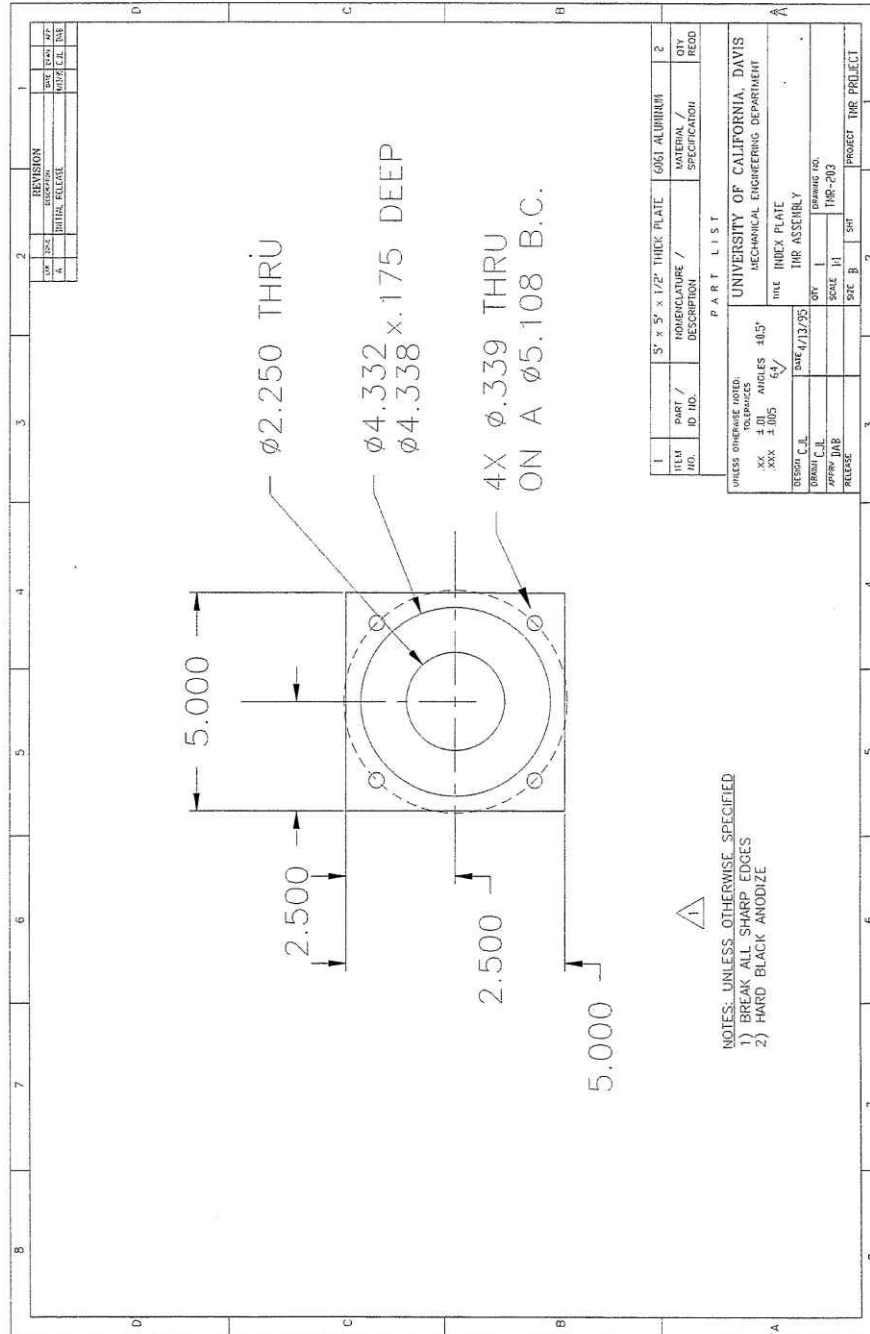


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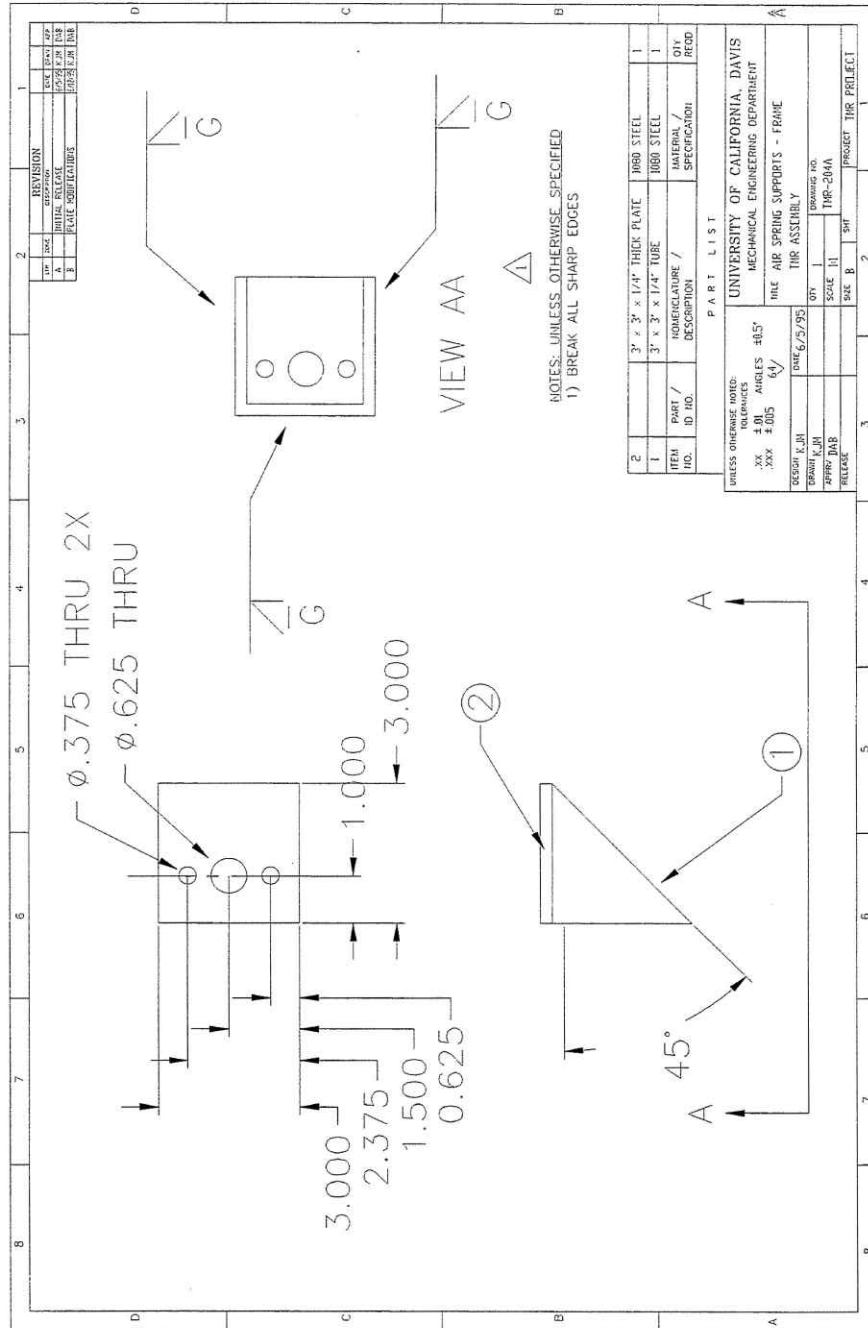


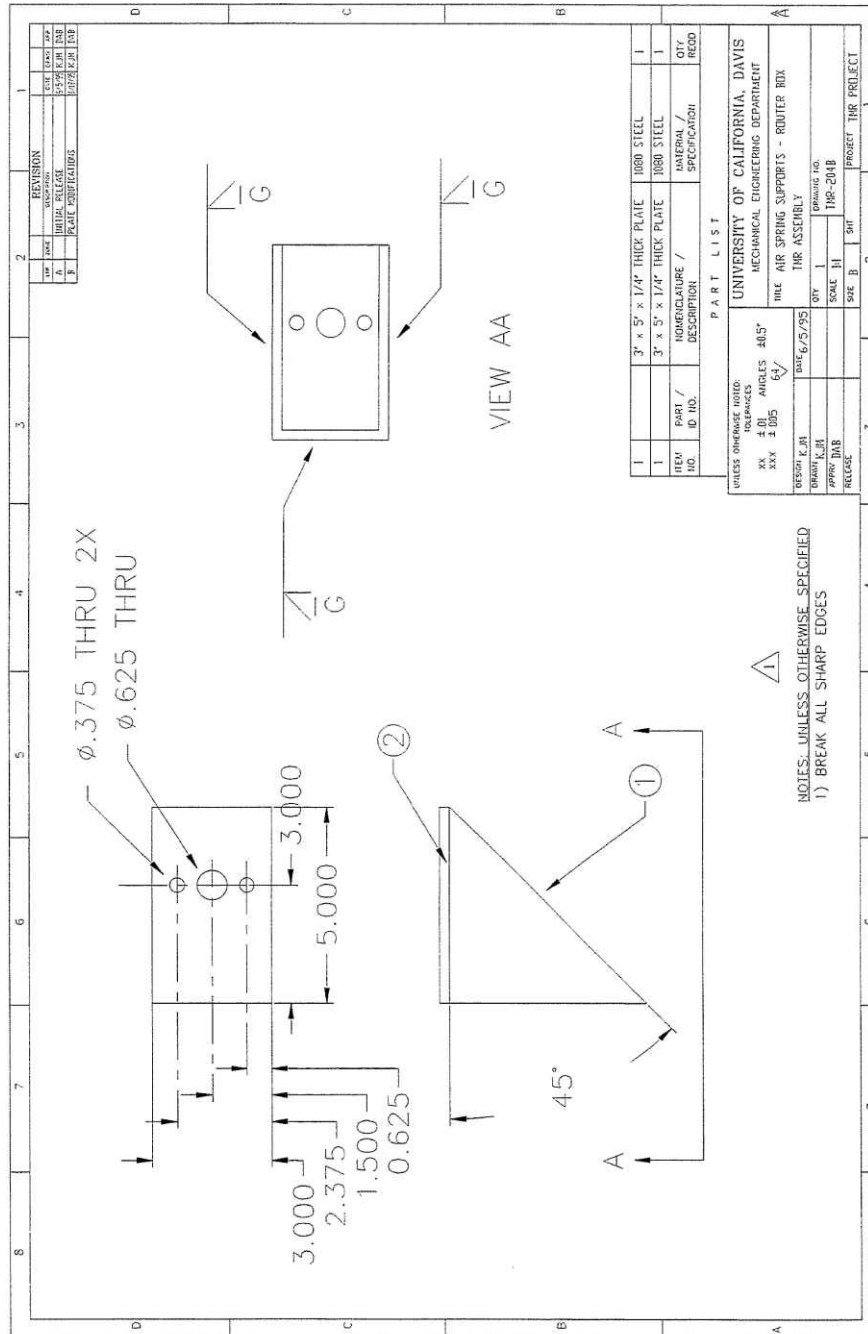




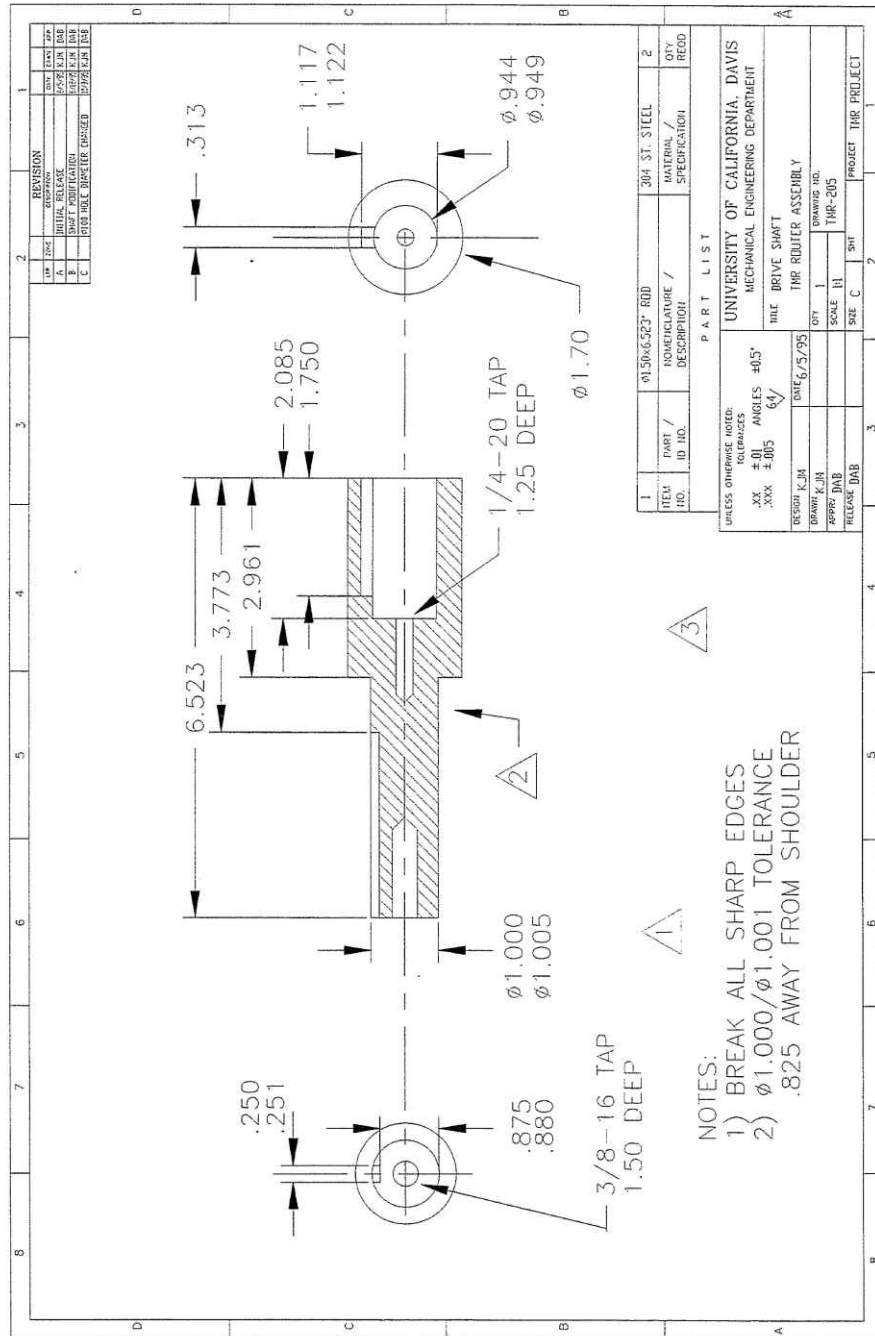


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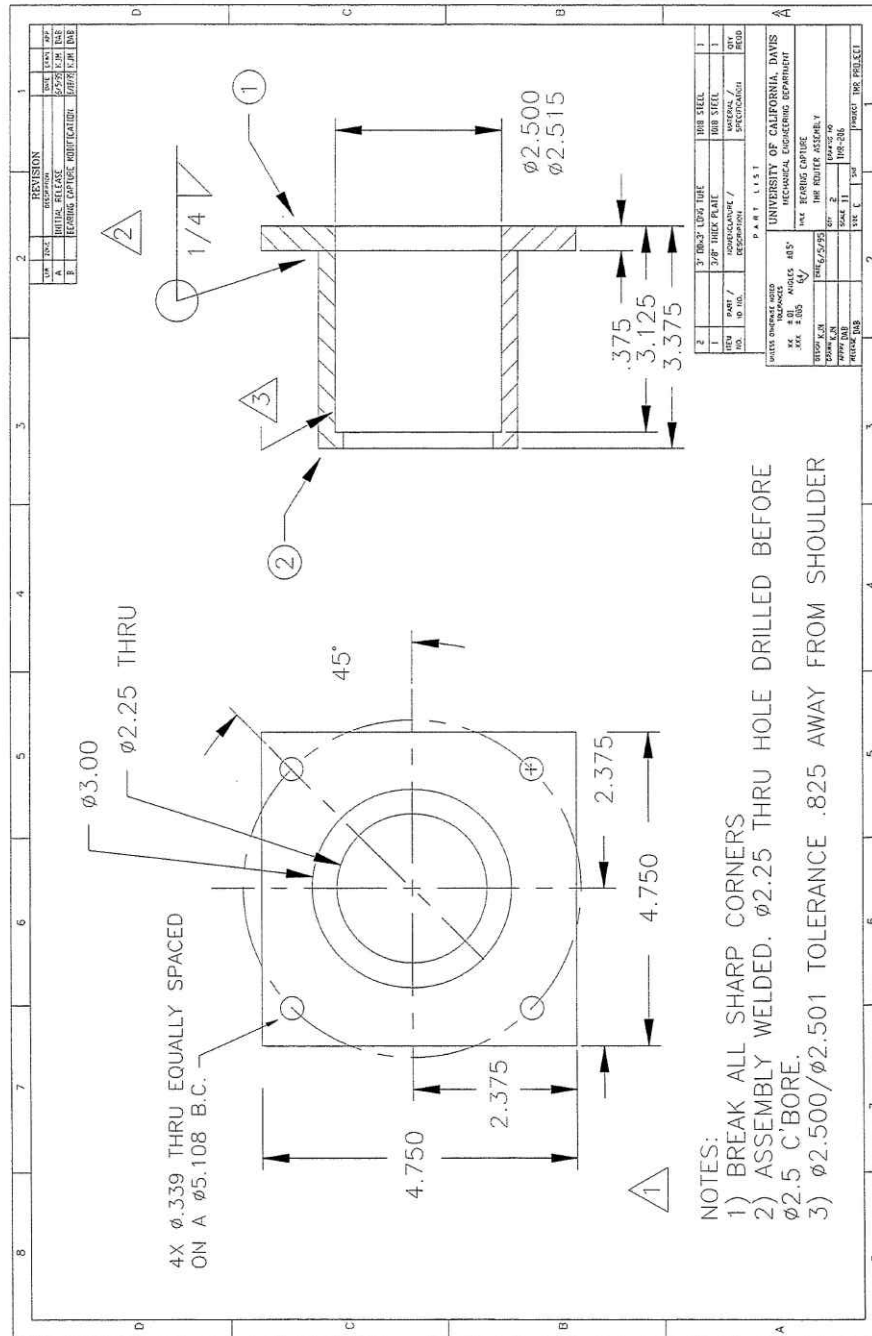




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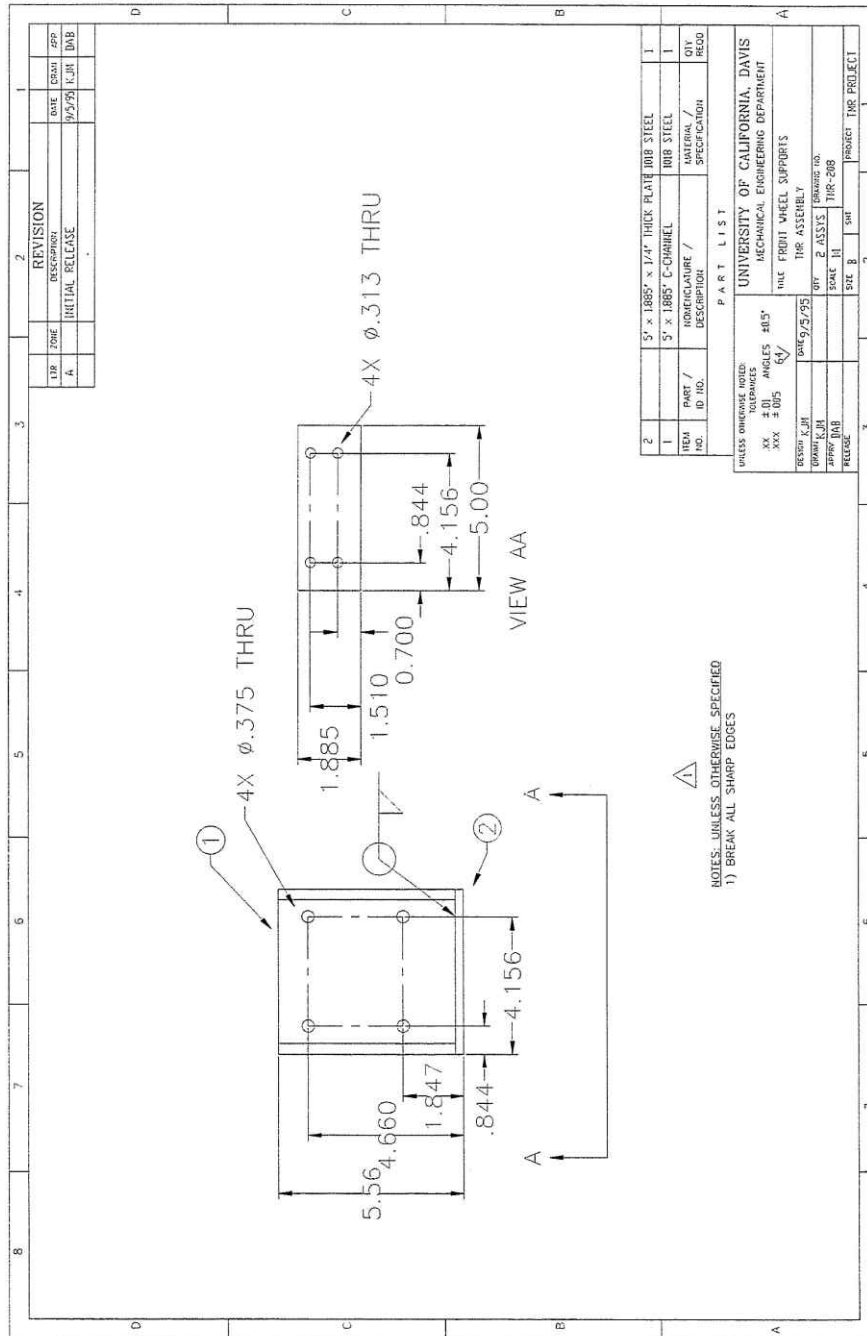


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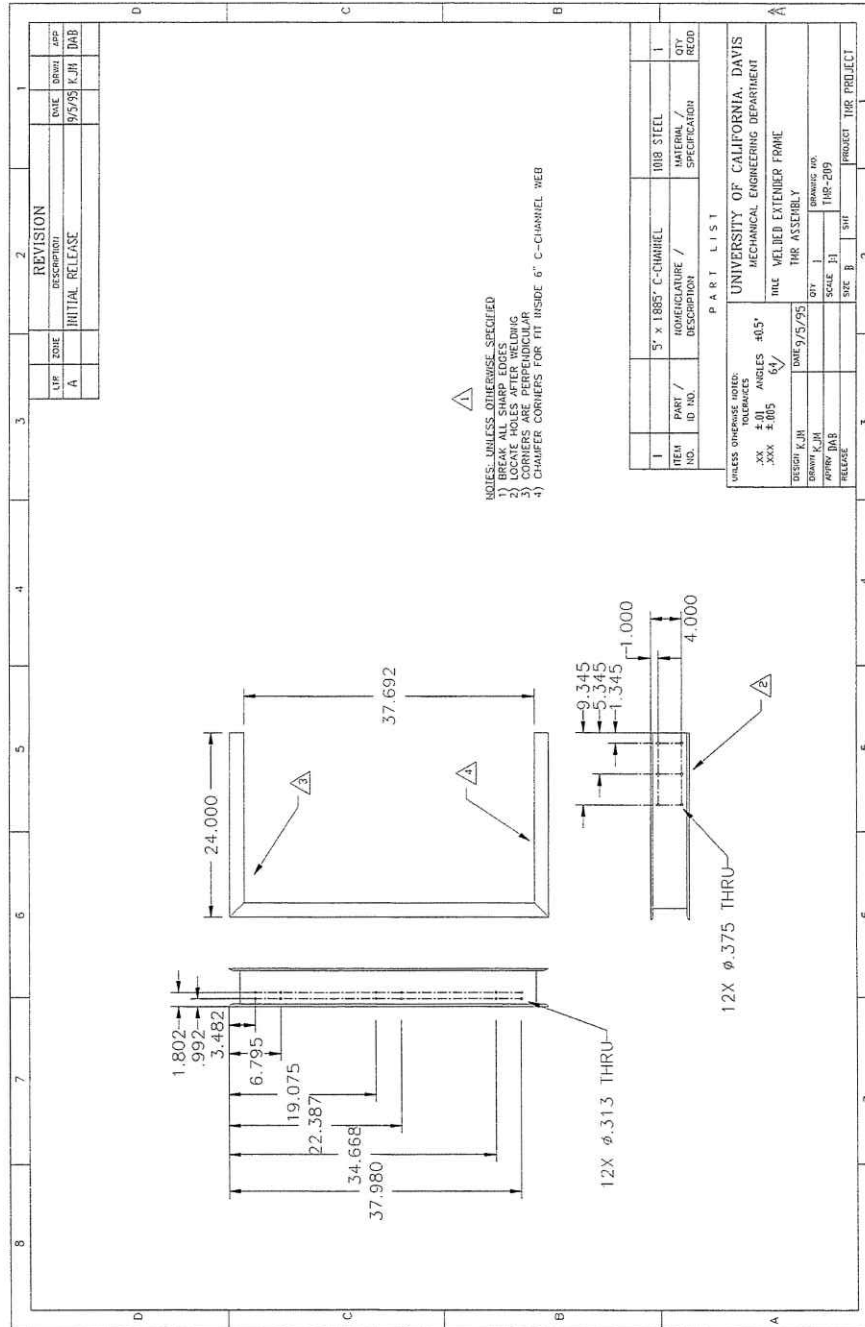






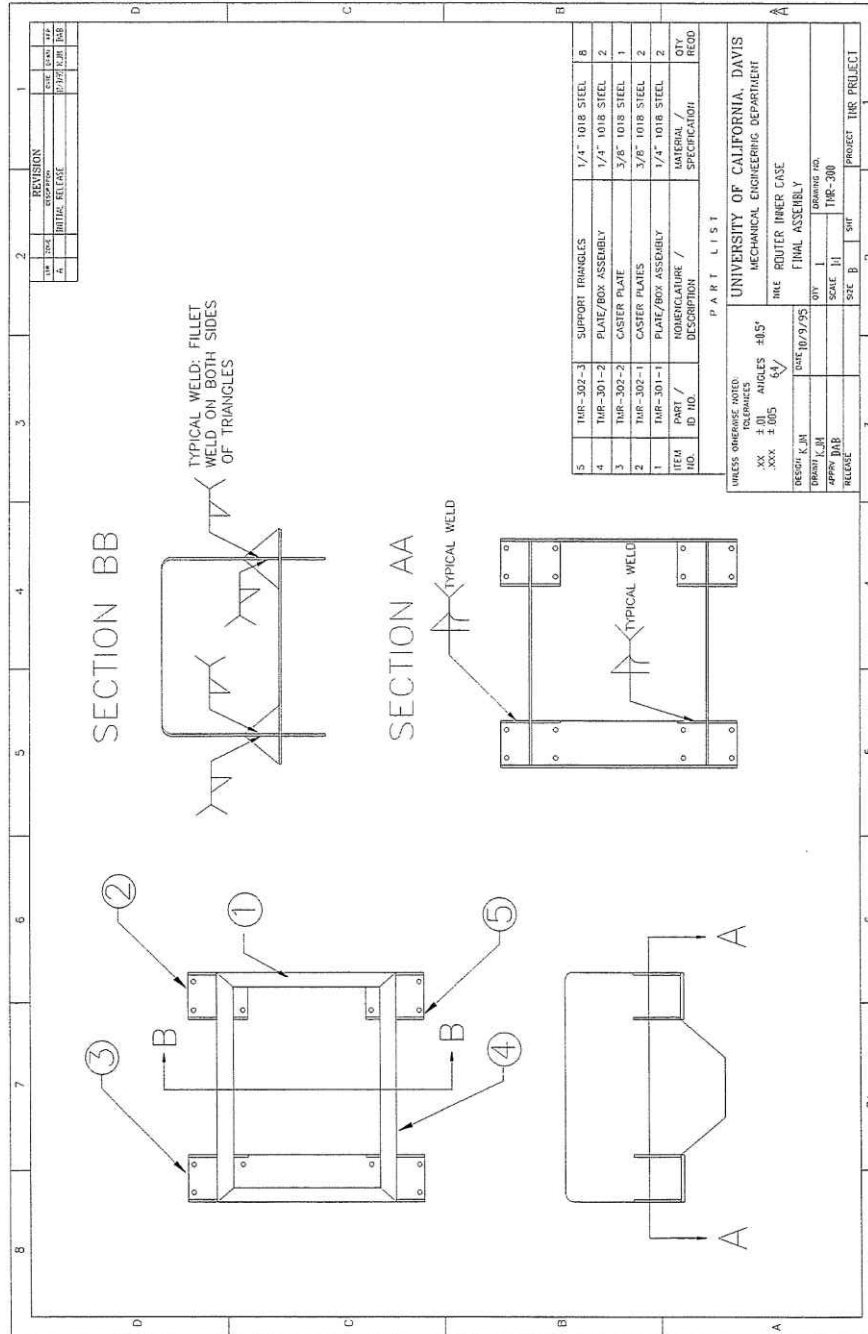


NOTES: UNLESS OTHERWISE SPECIFIED  
1) BREAK ALL SHARP EDGES

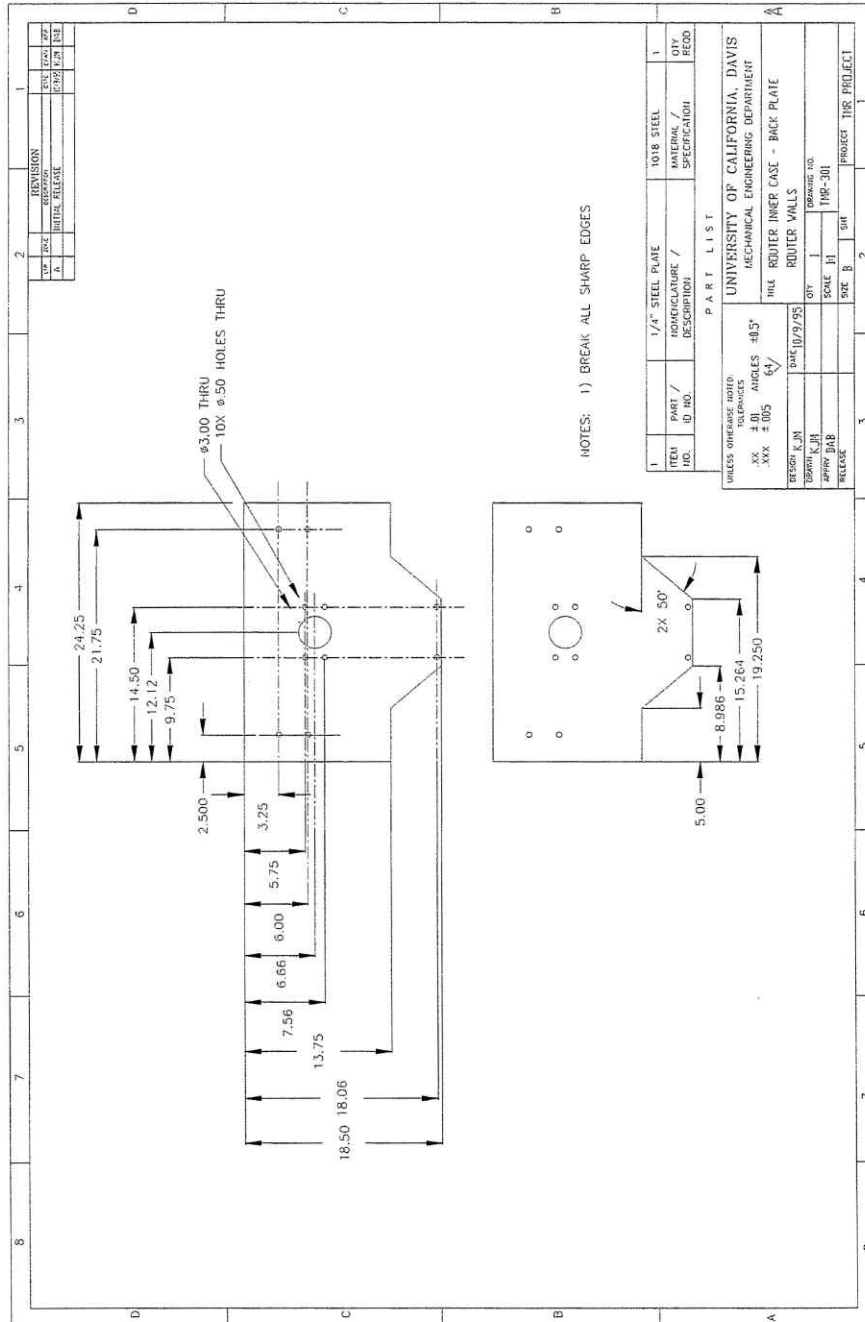


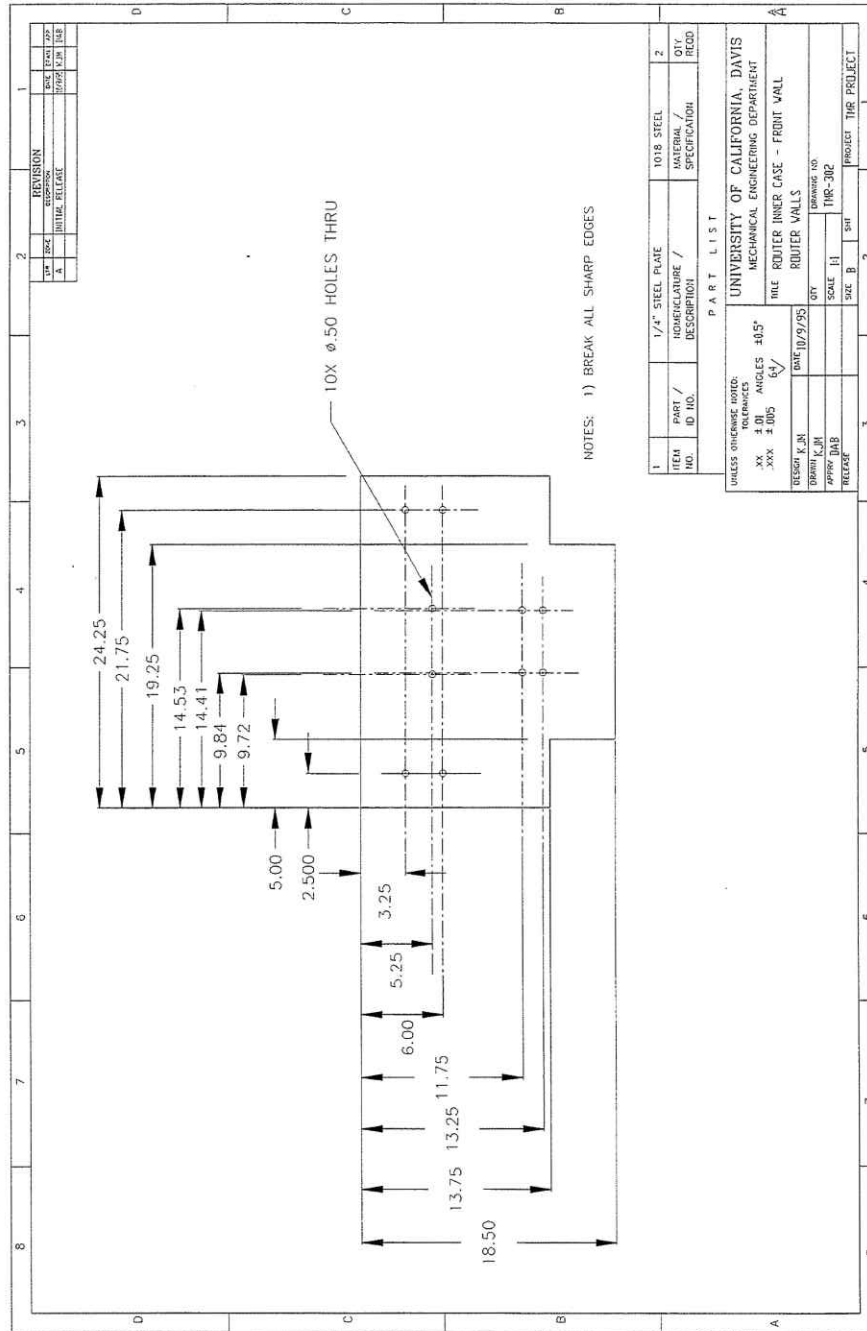


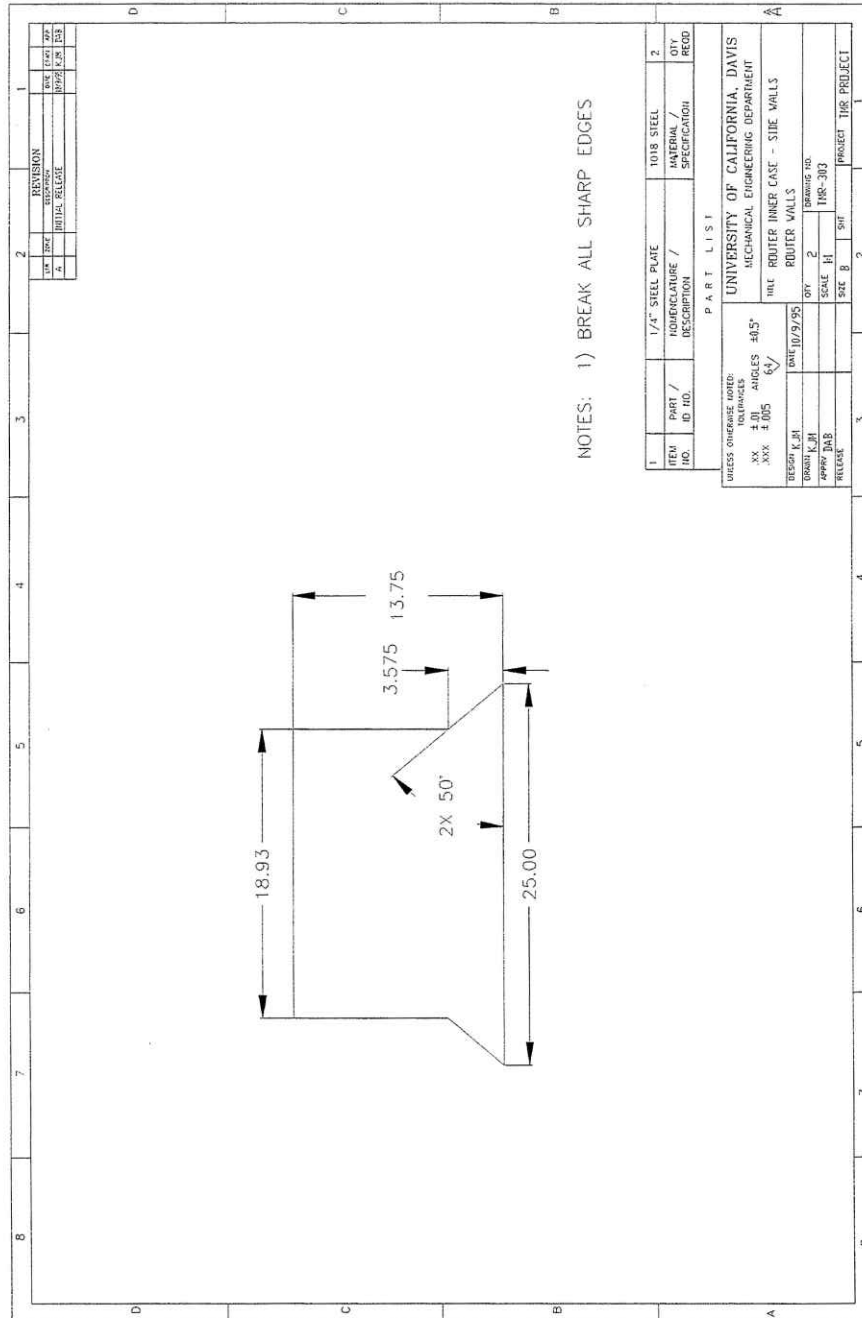




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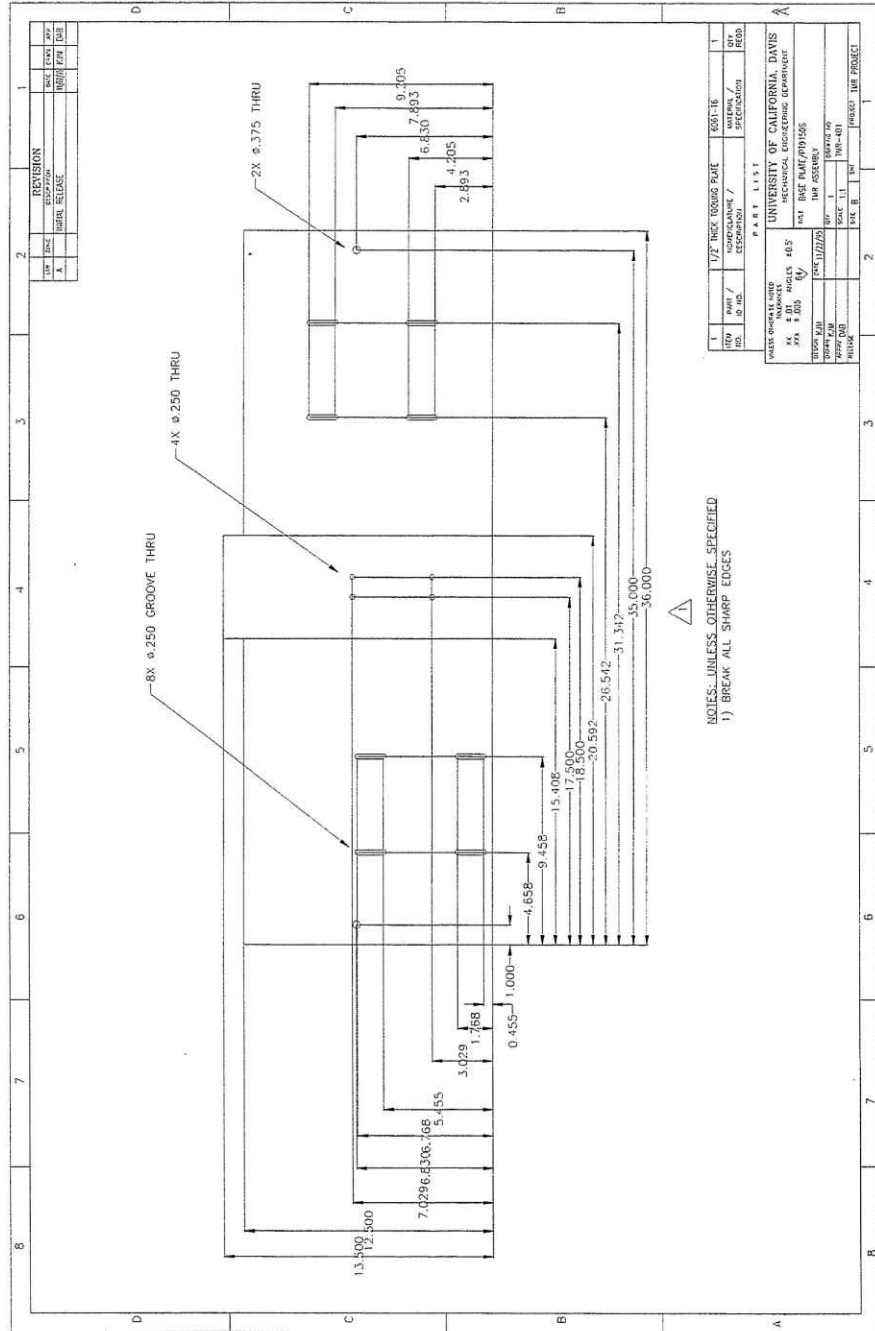




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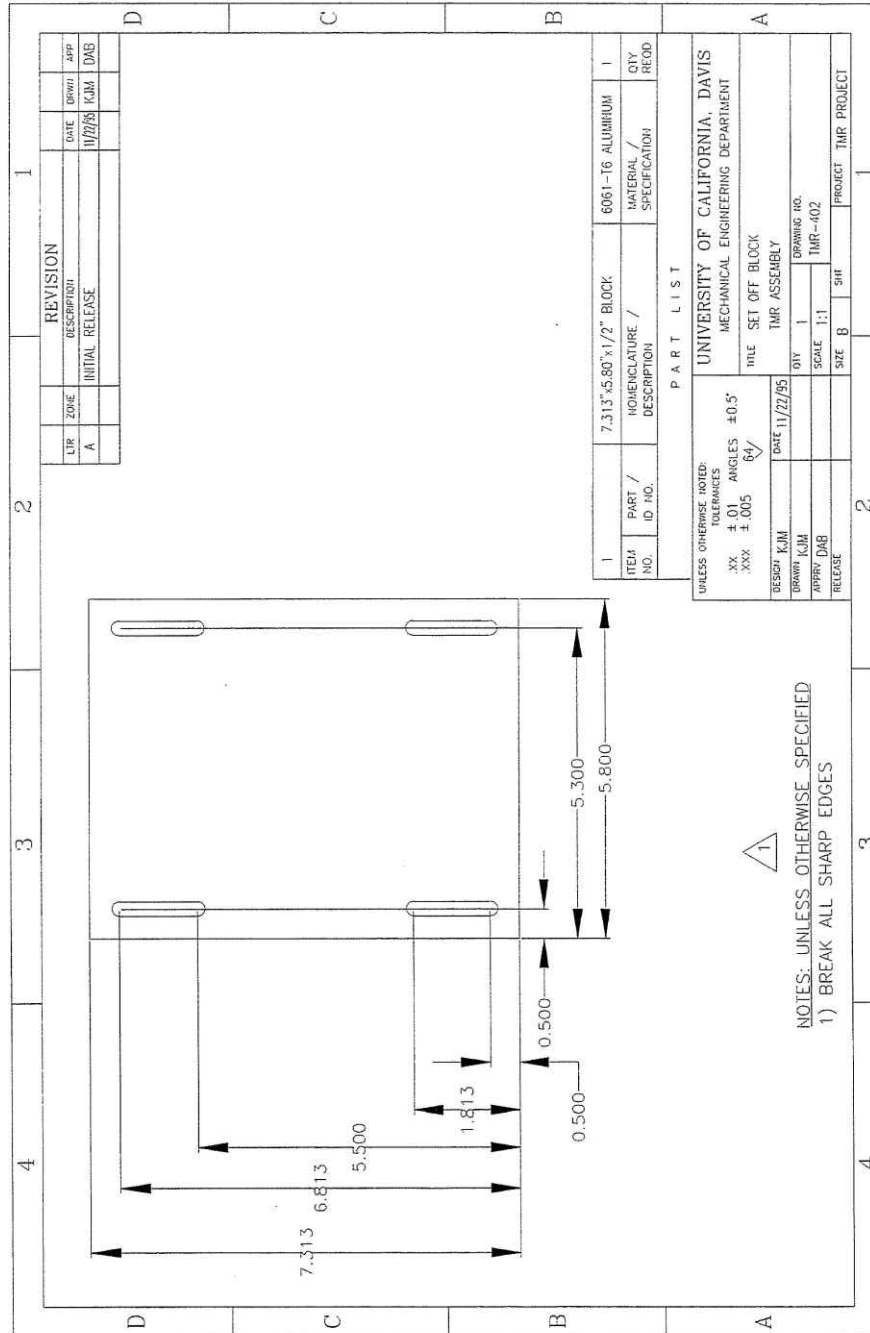


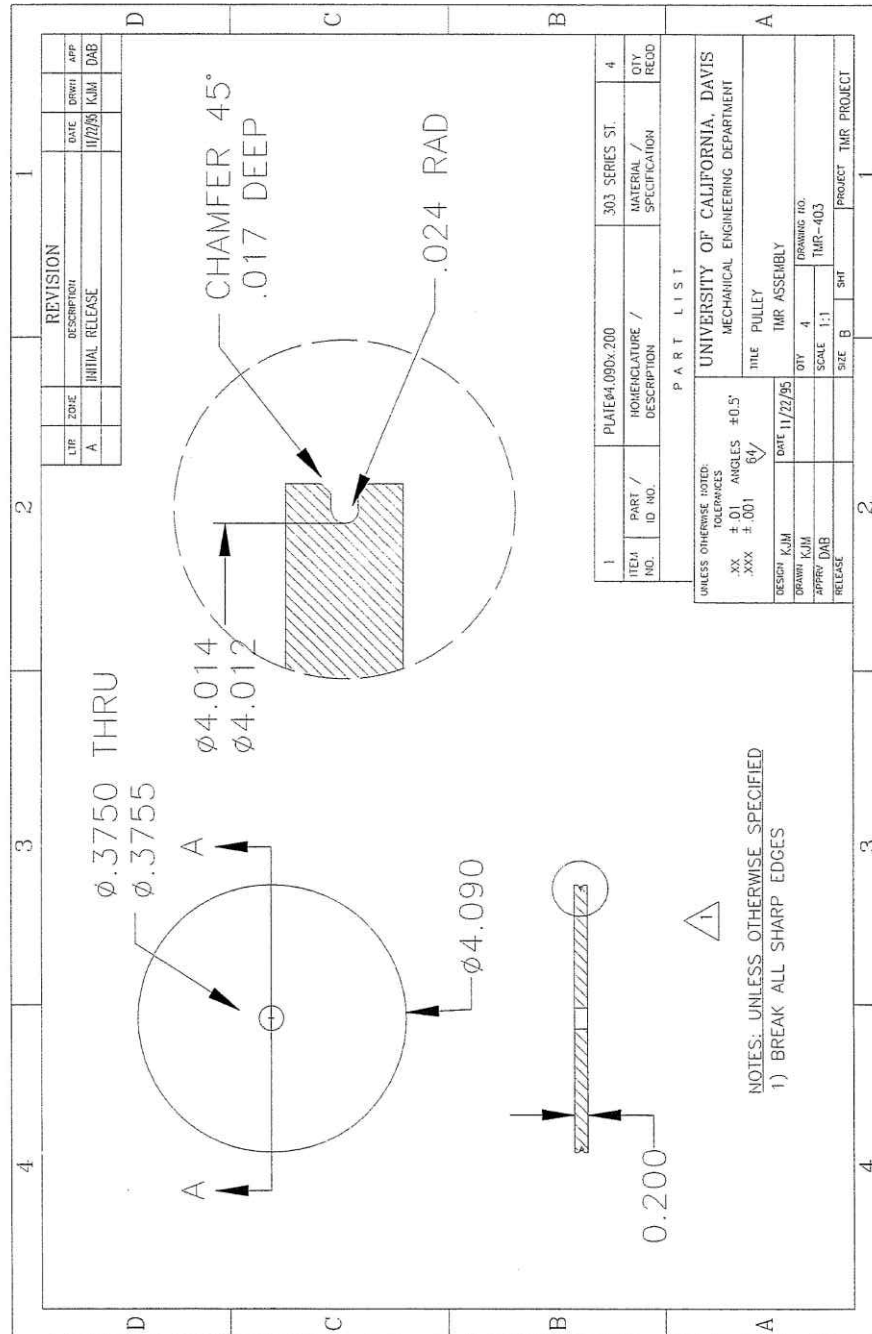


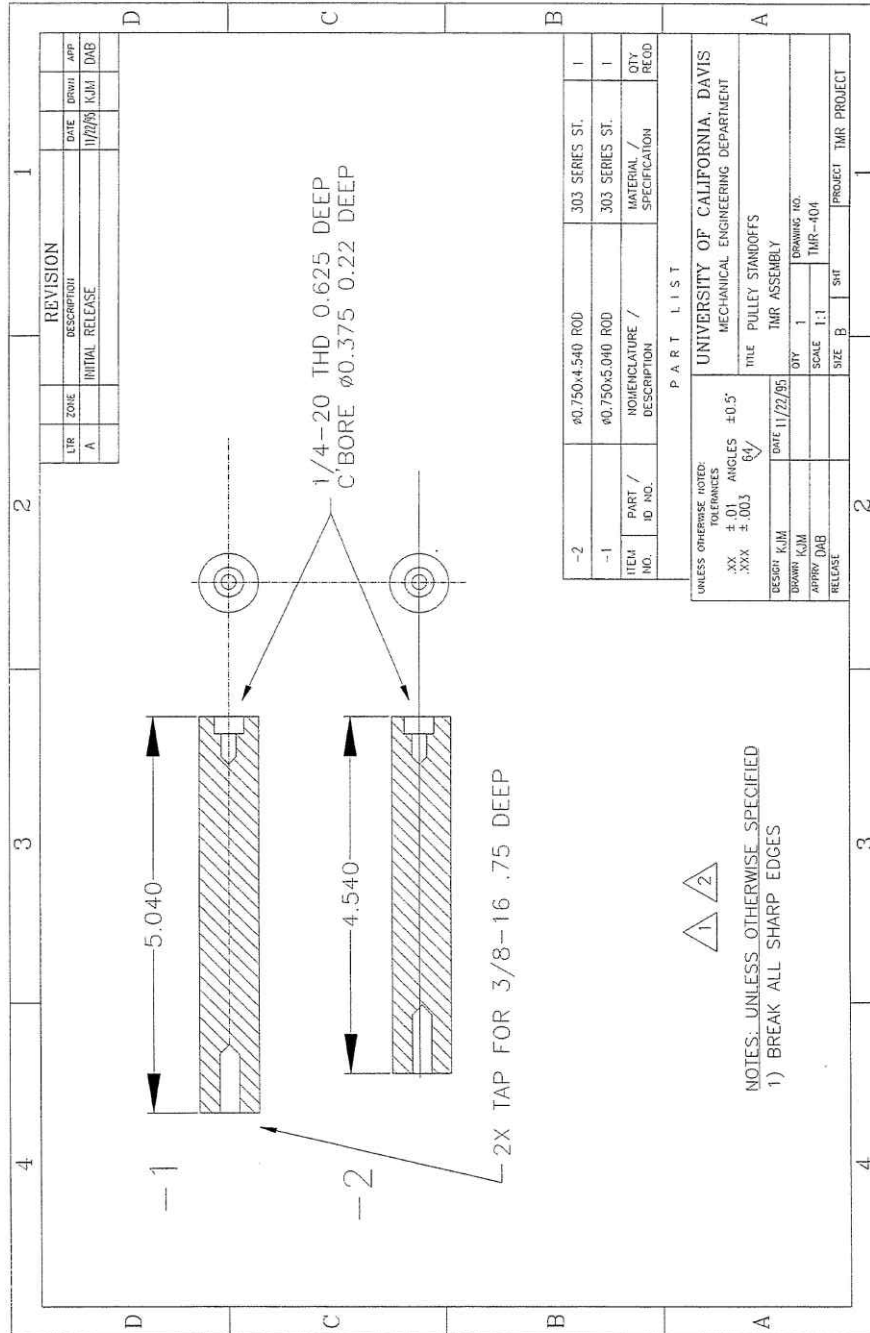
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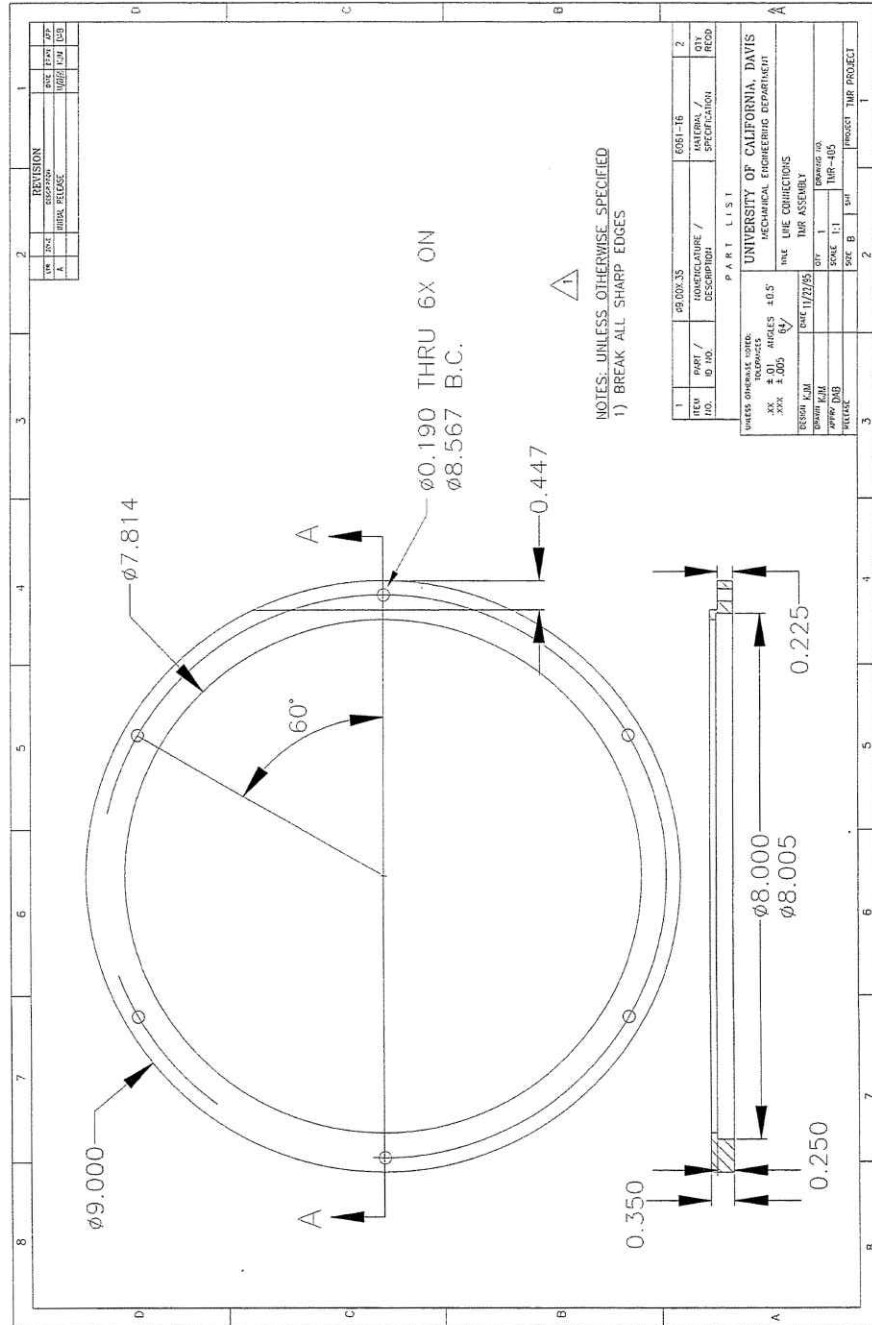
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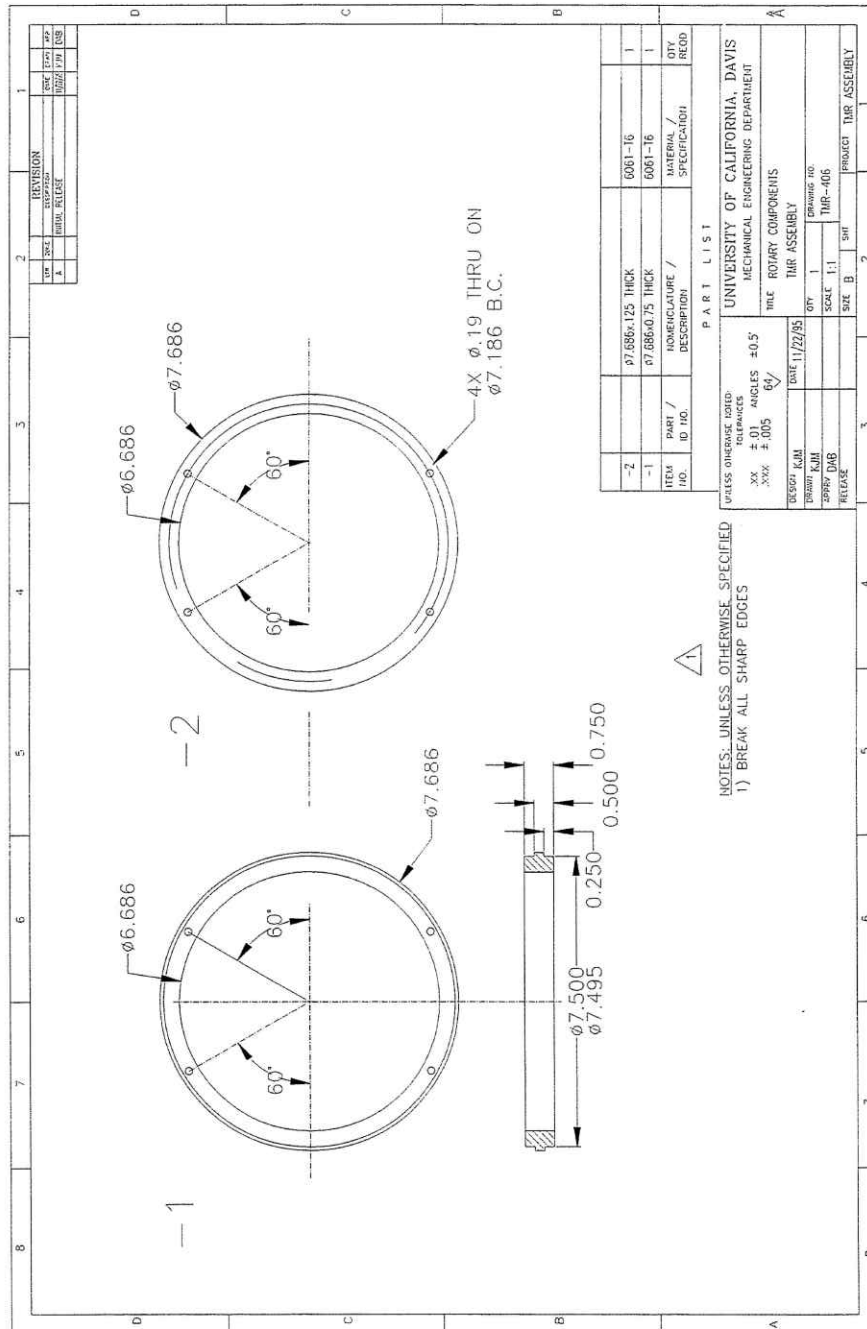


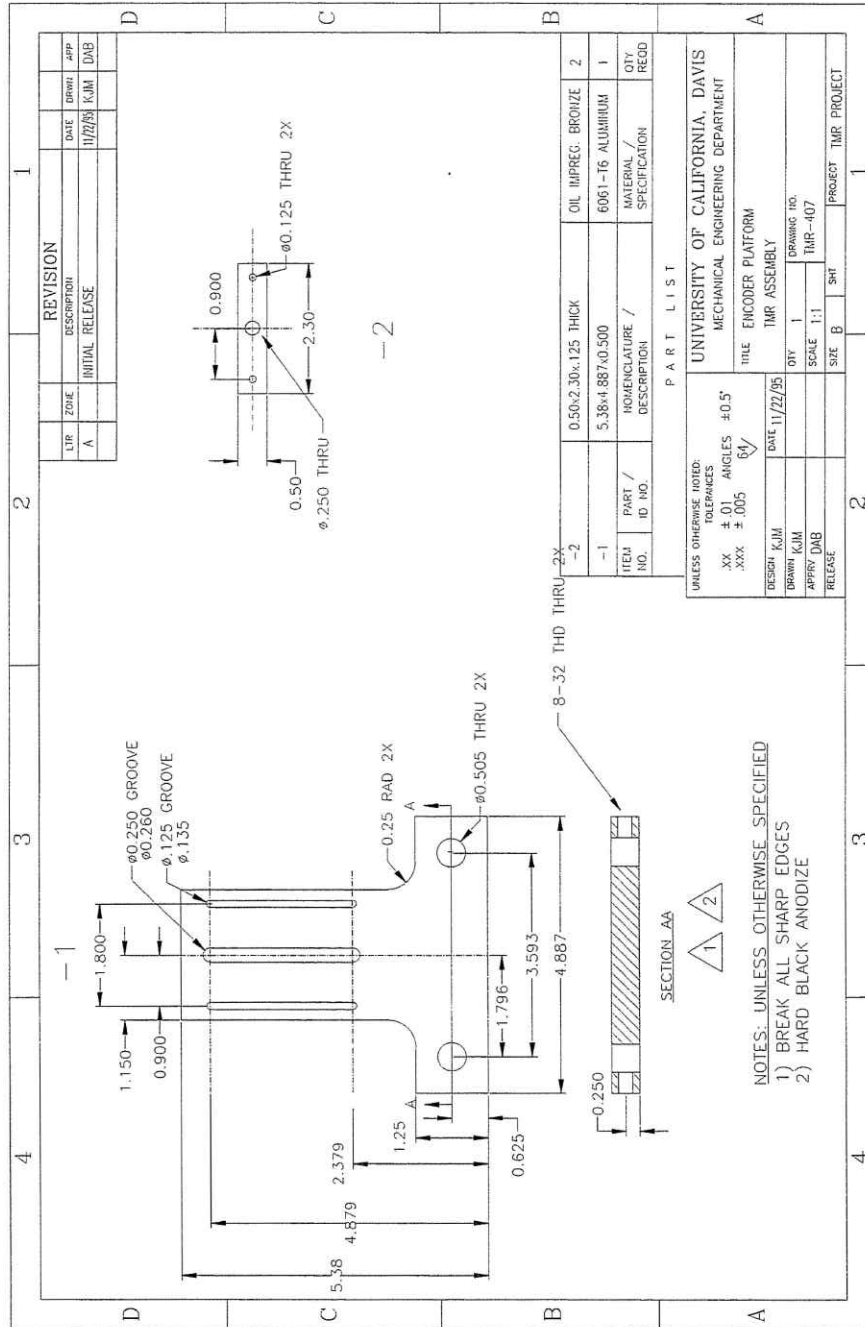




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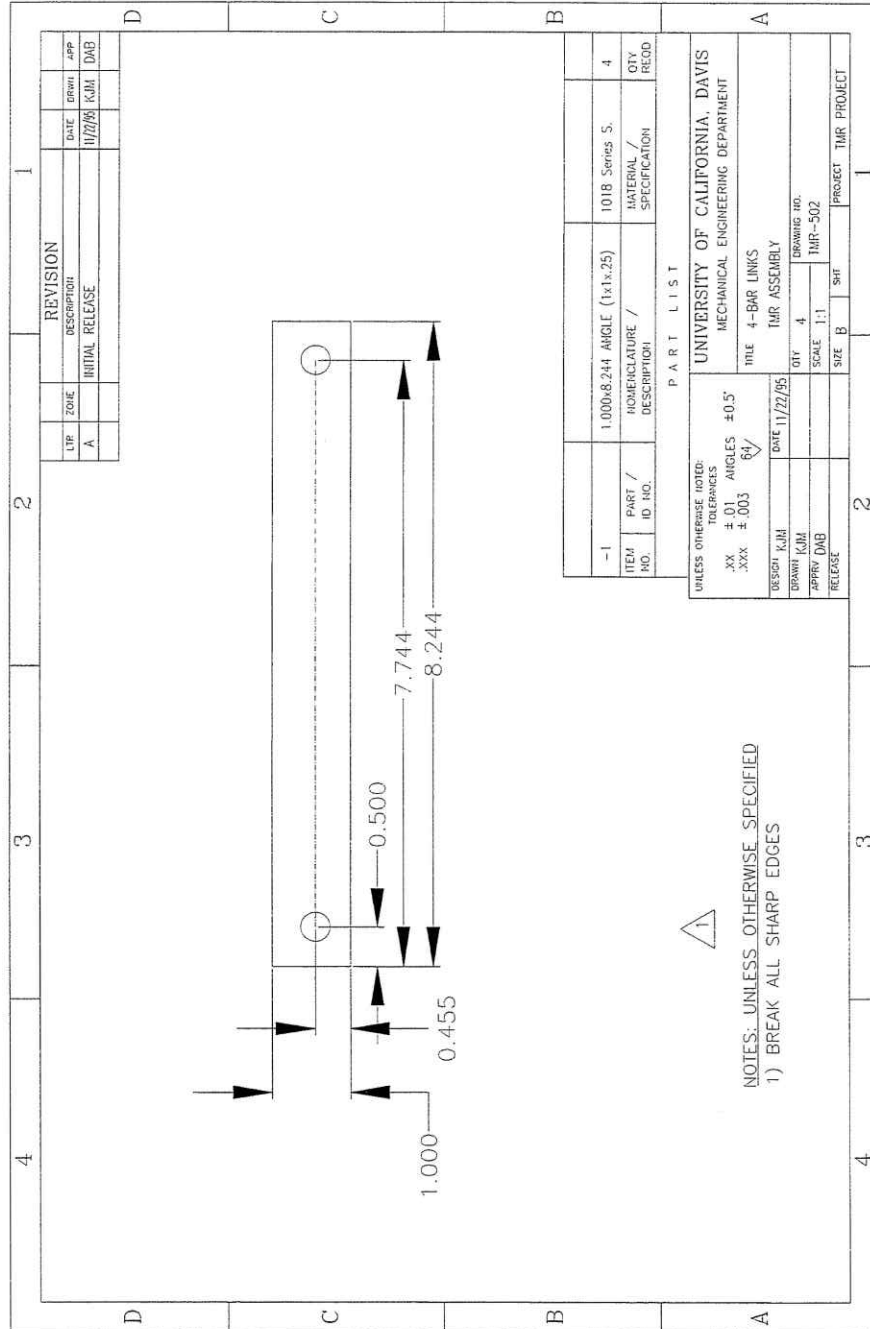


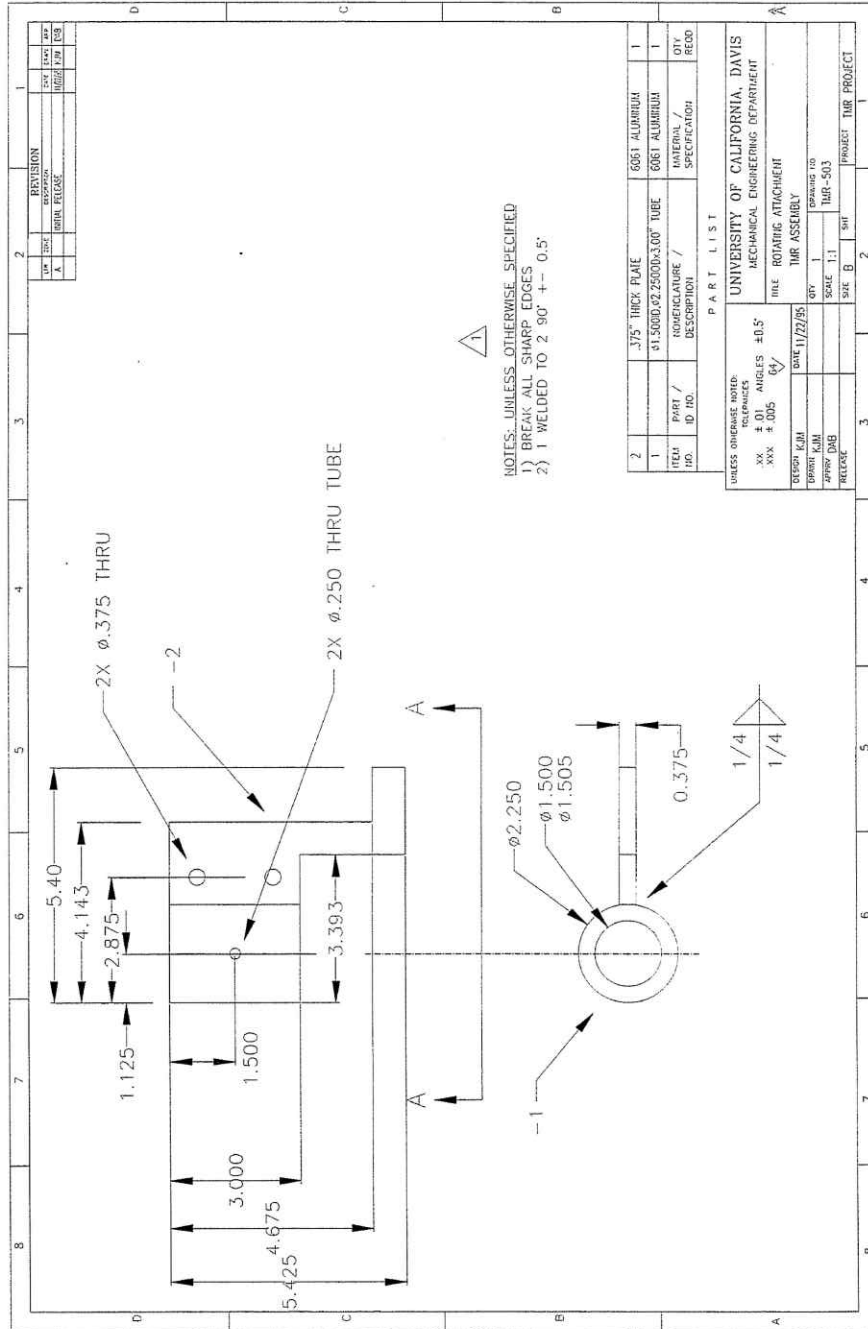


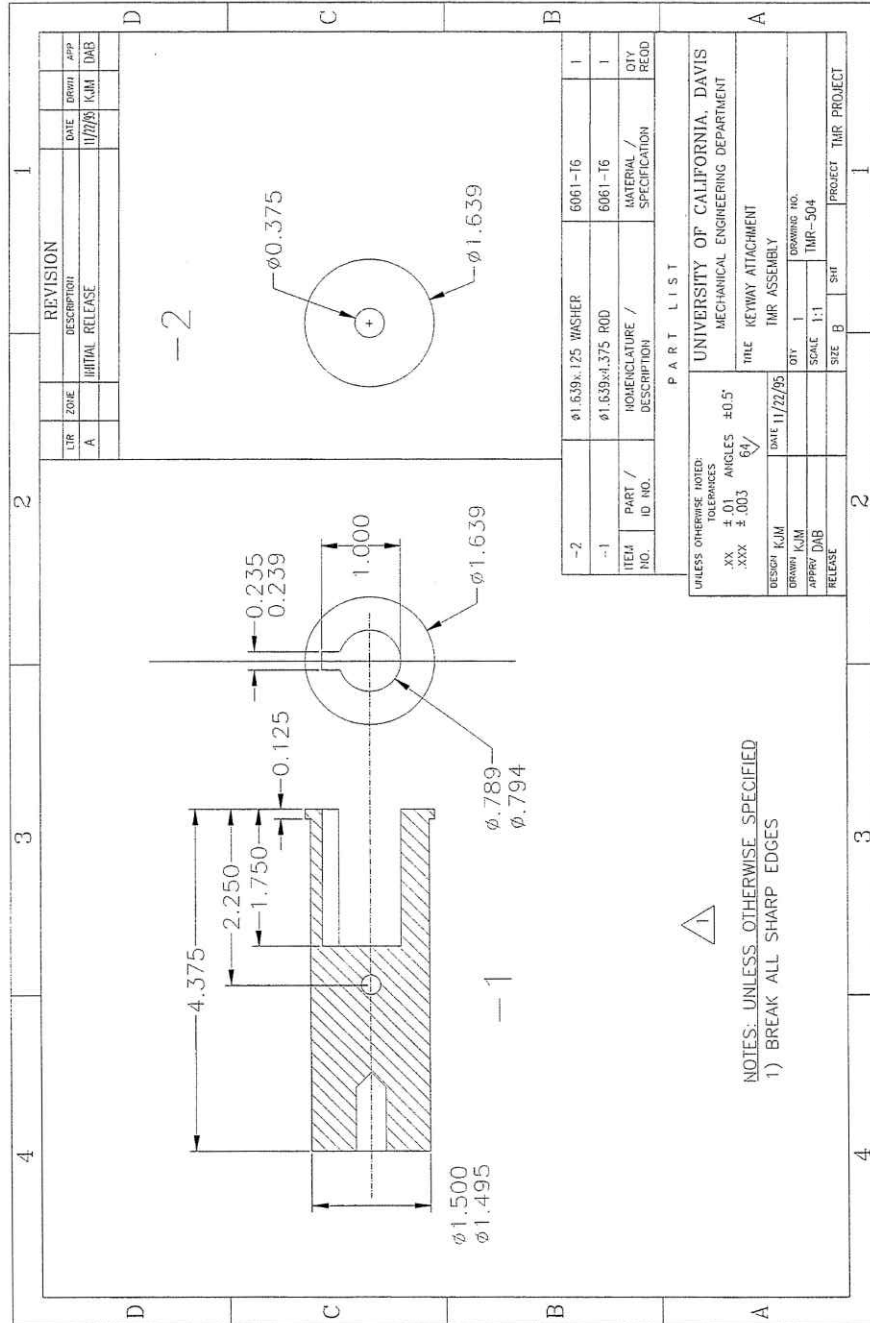




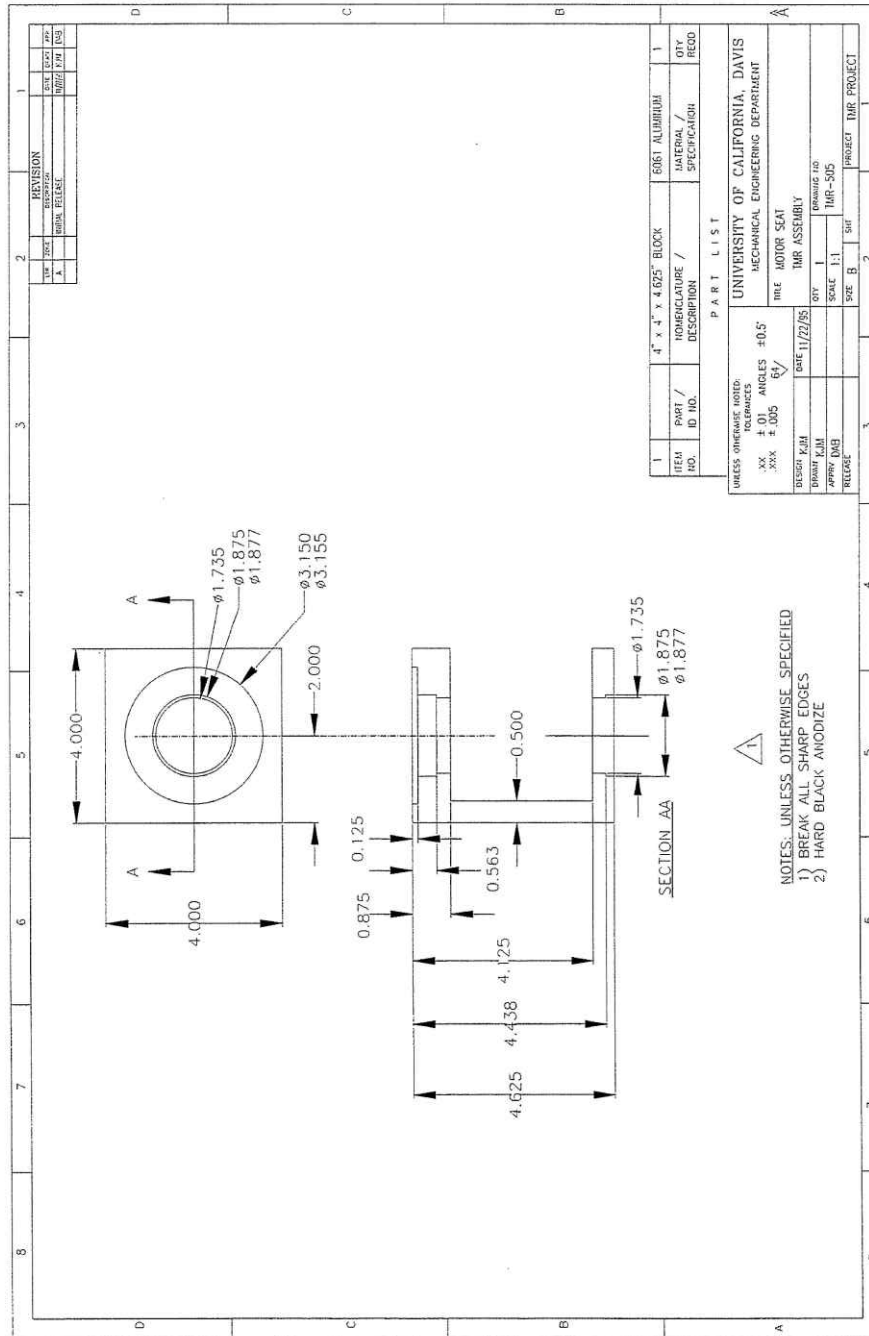




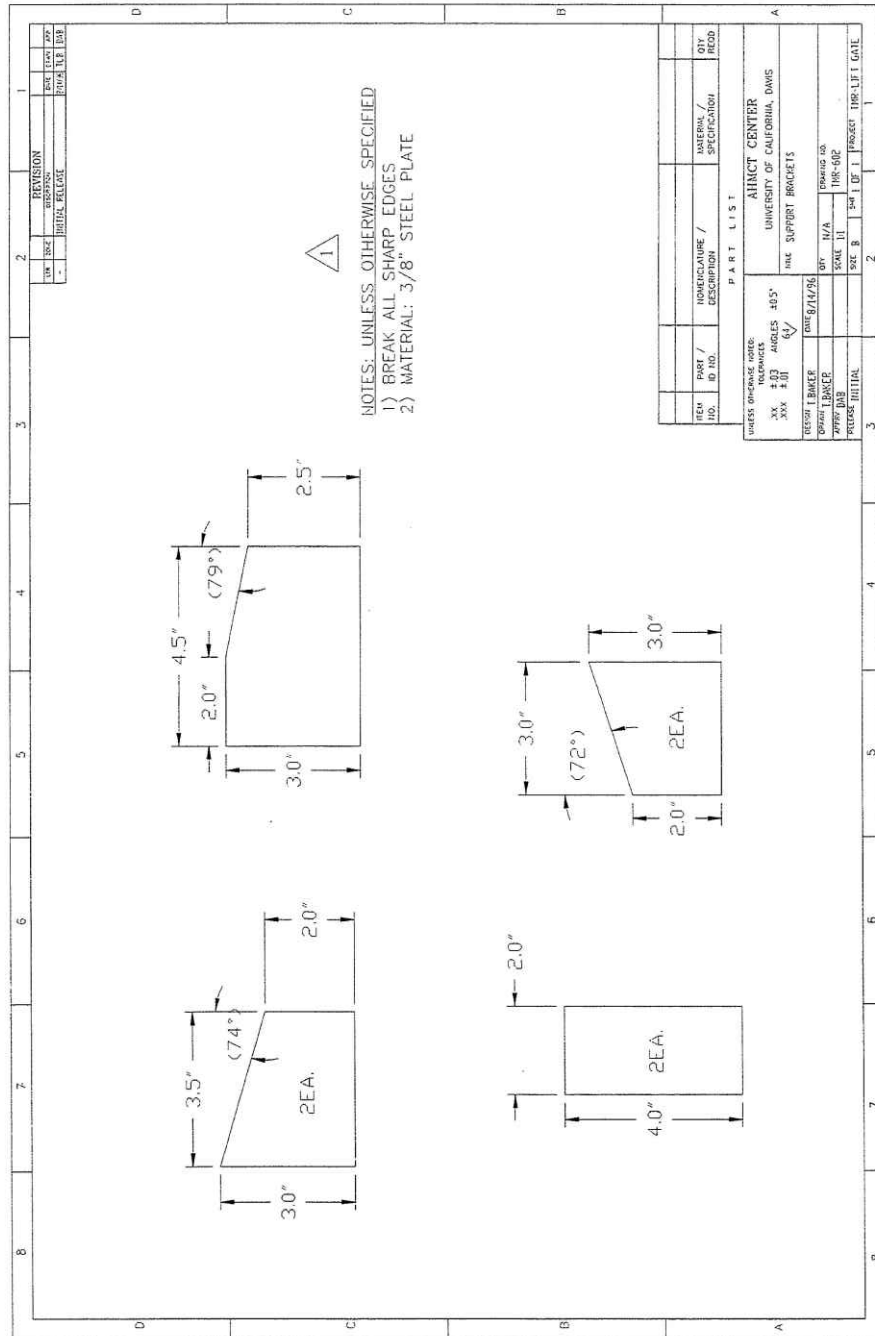




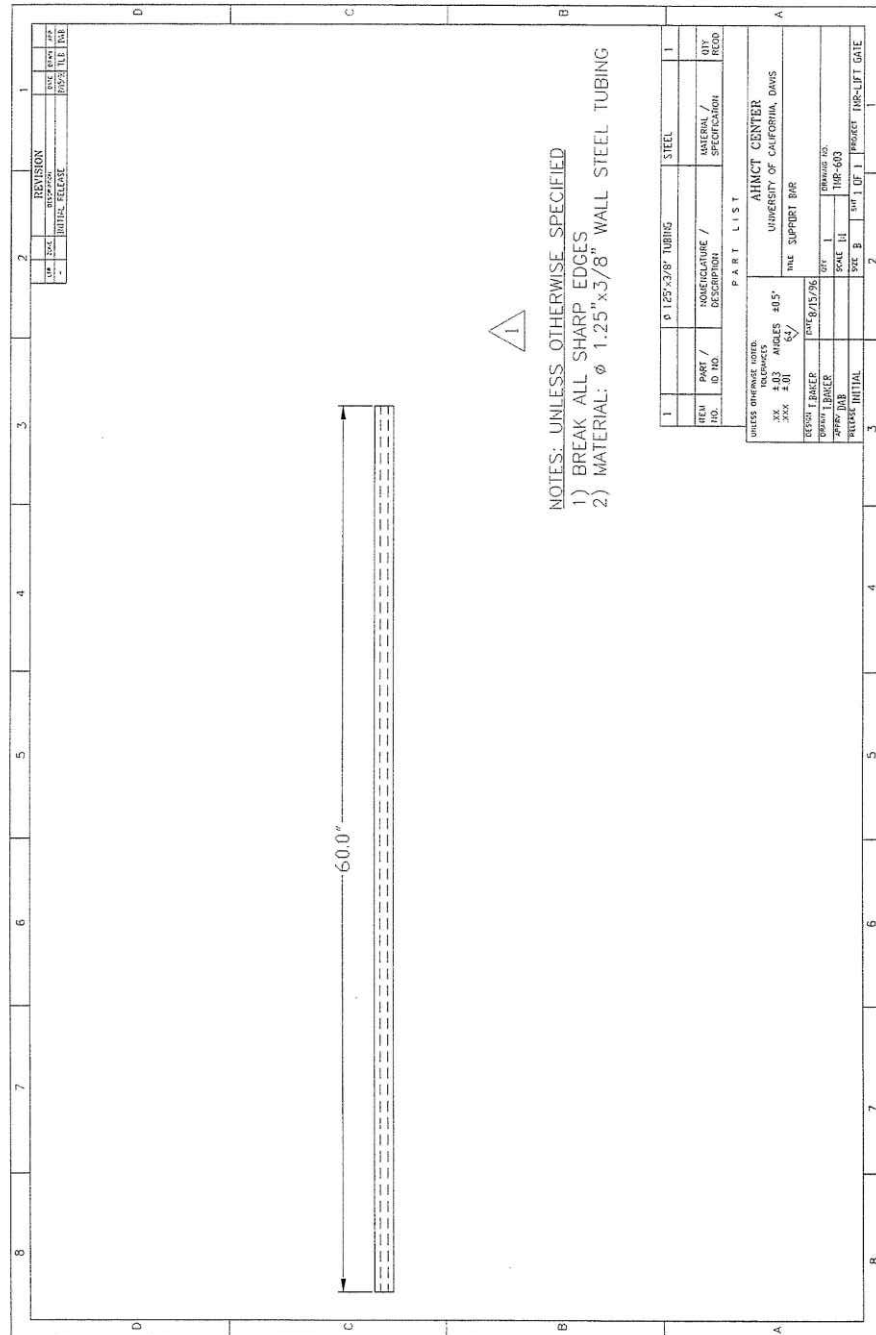
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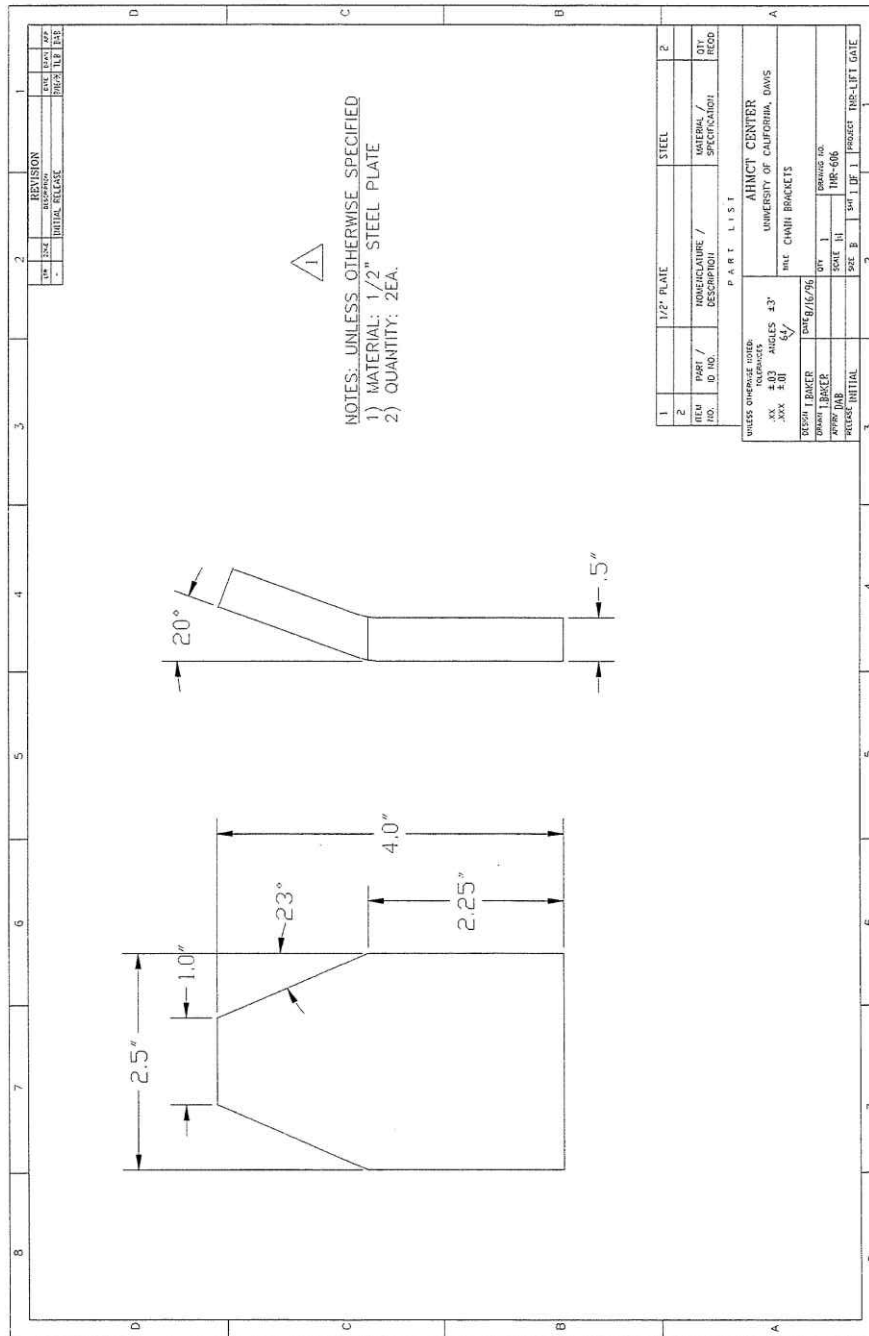


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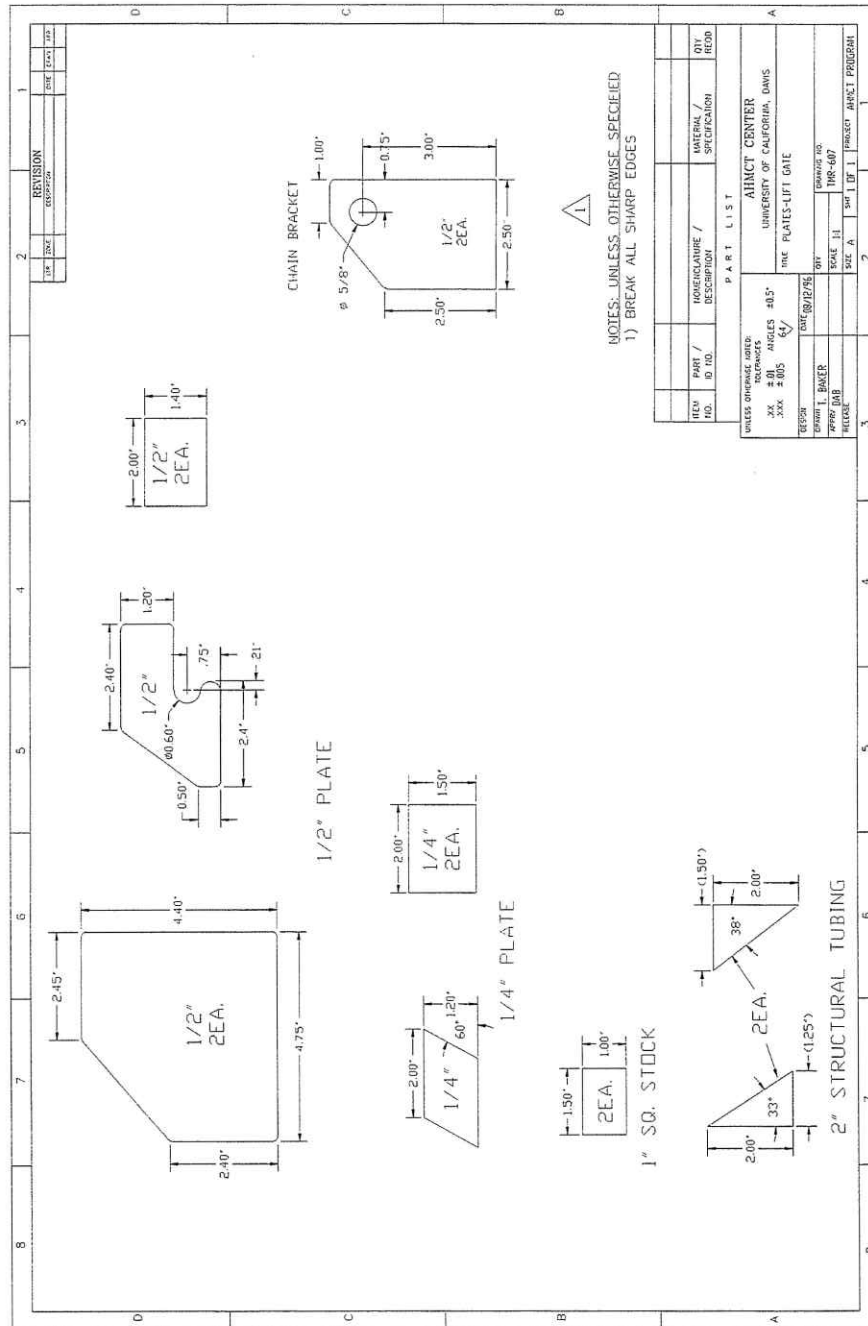




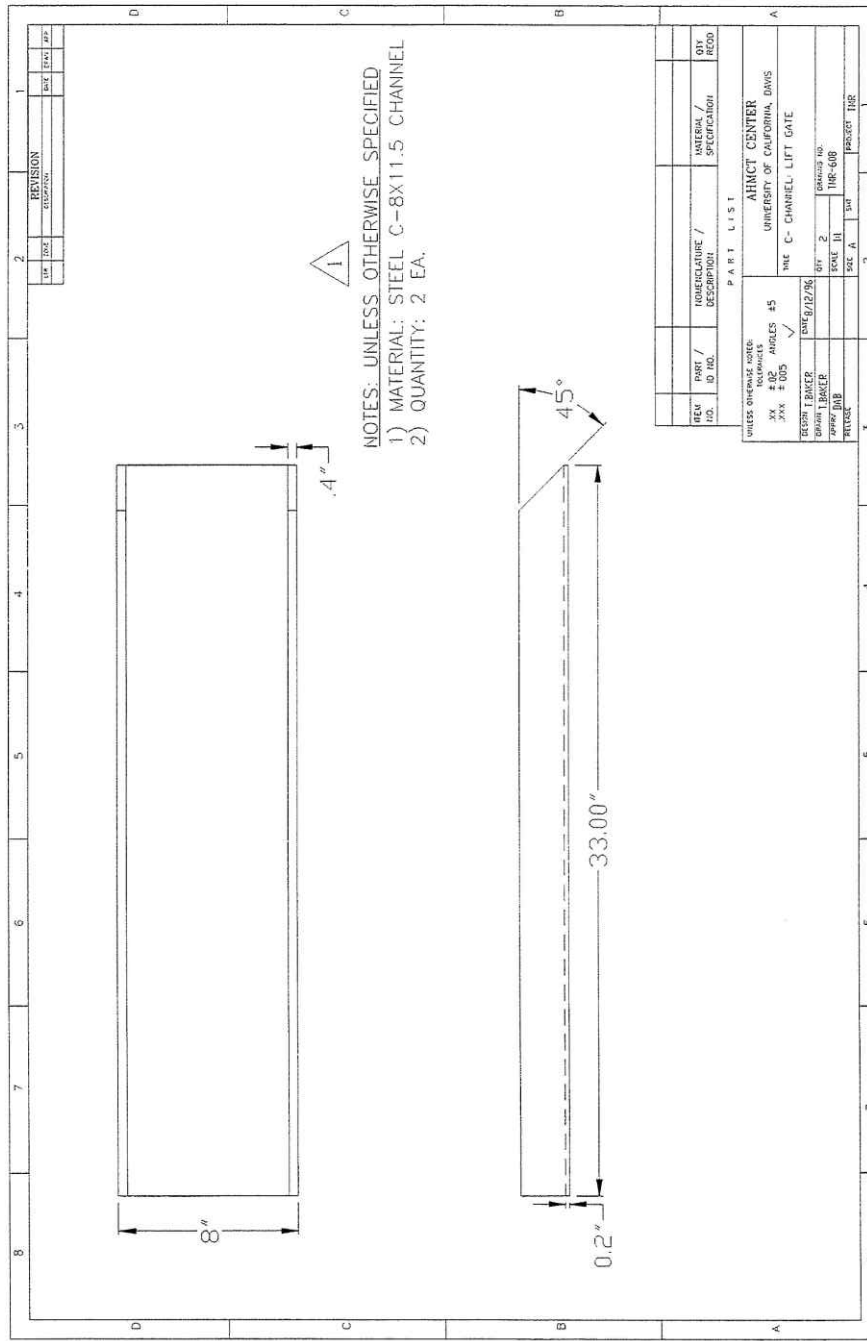




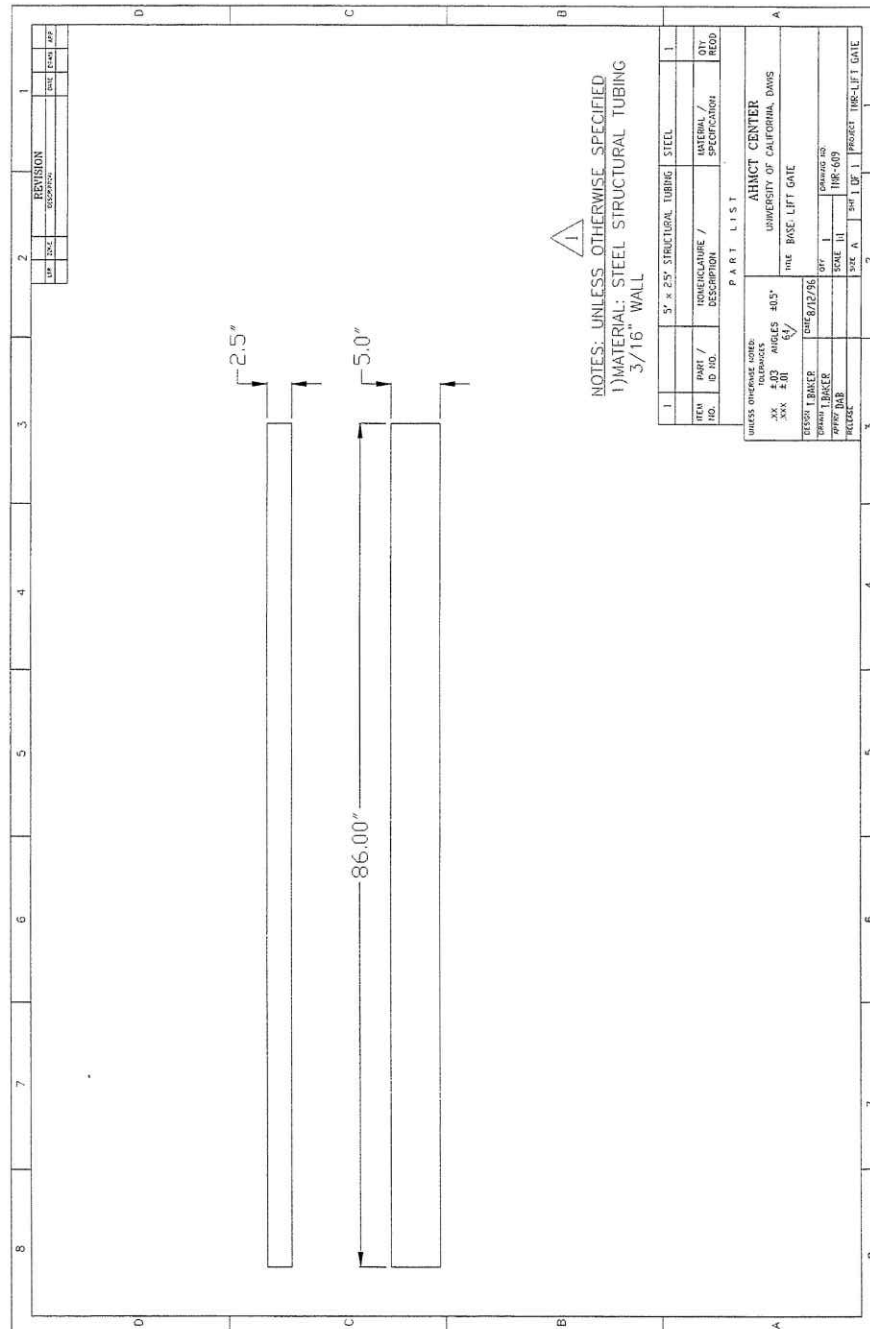
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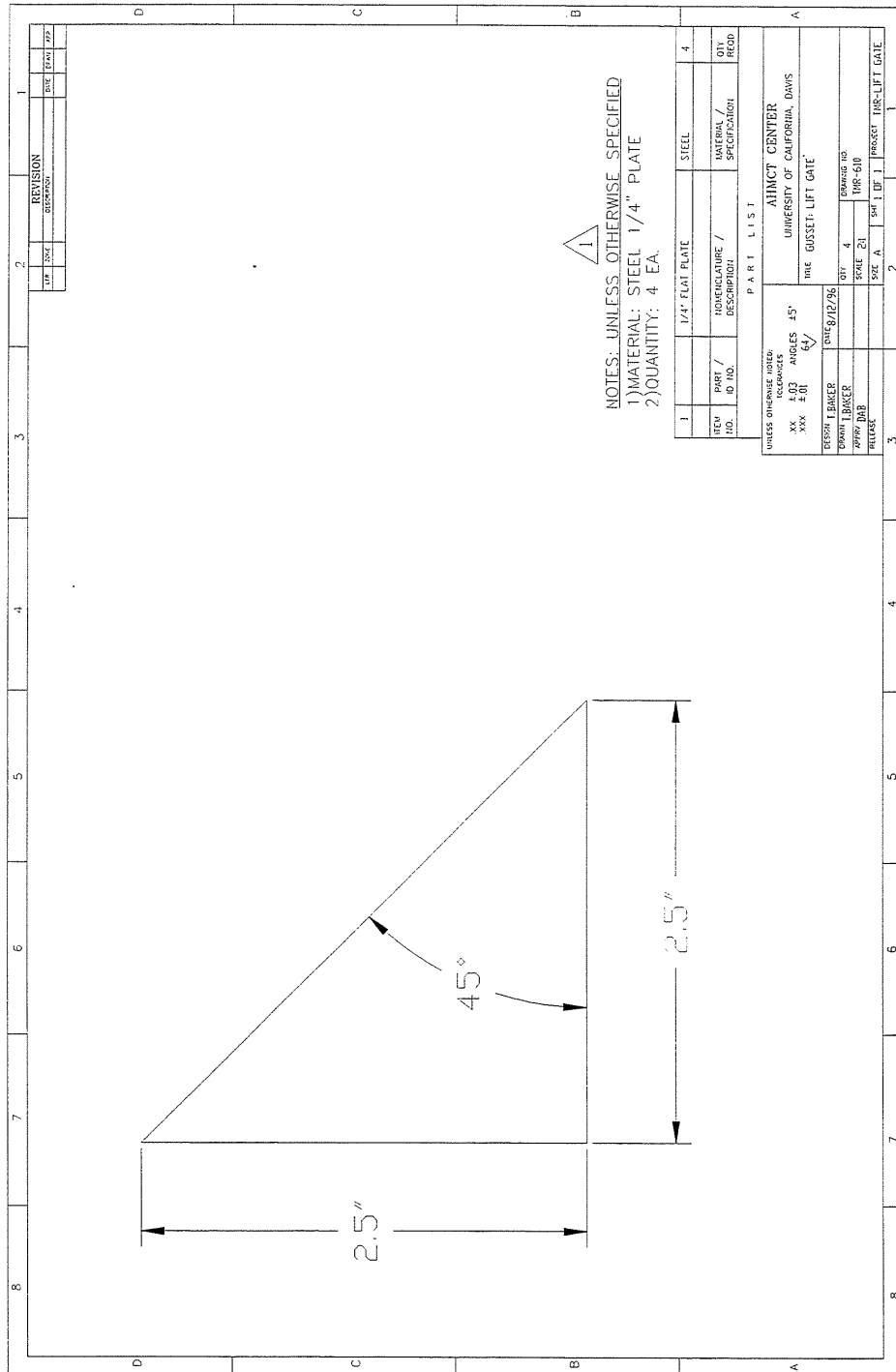
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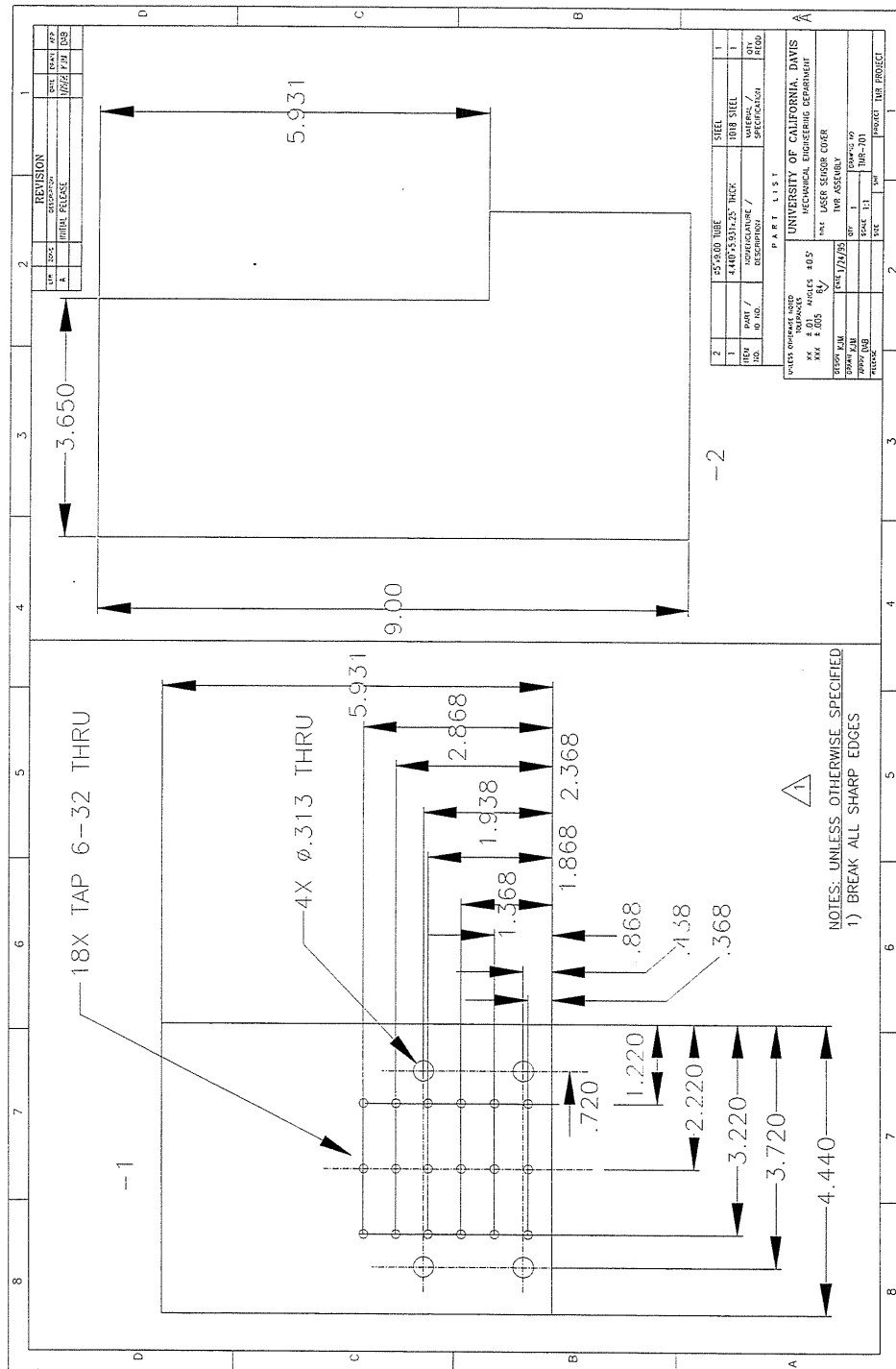
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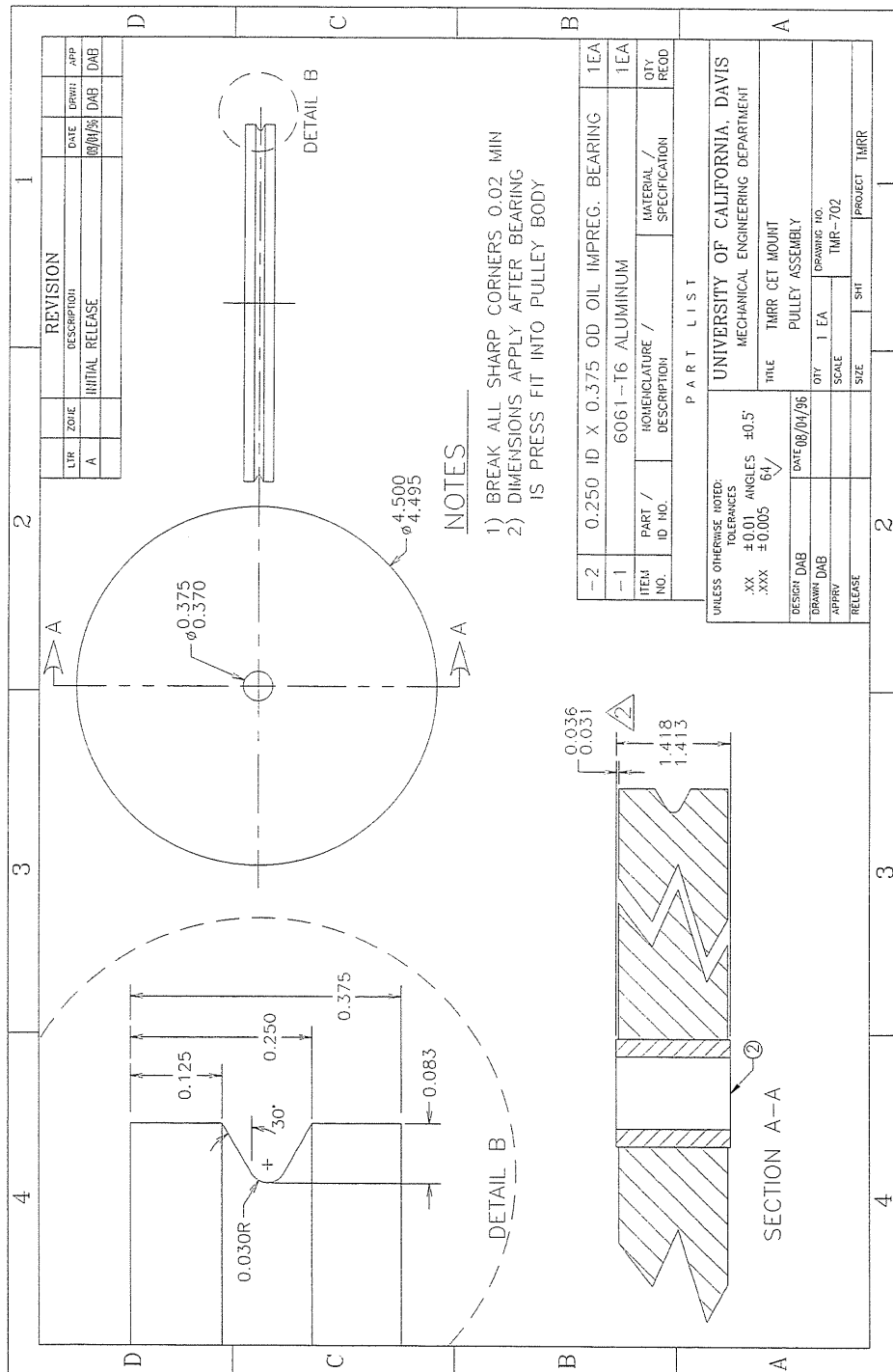


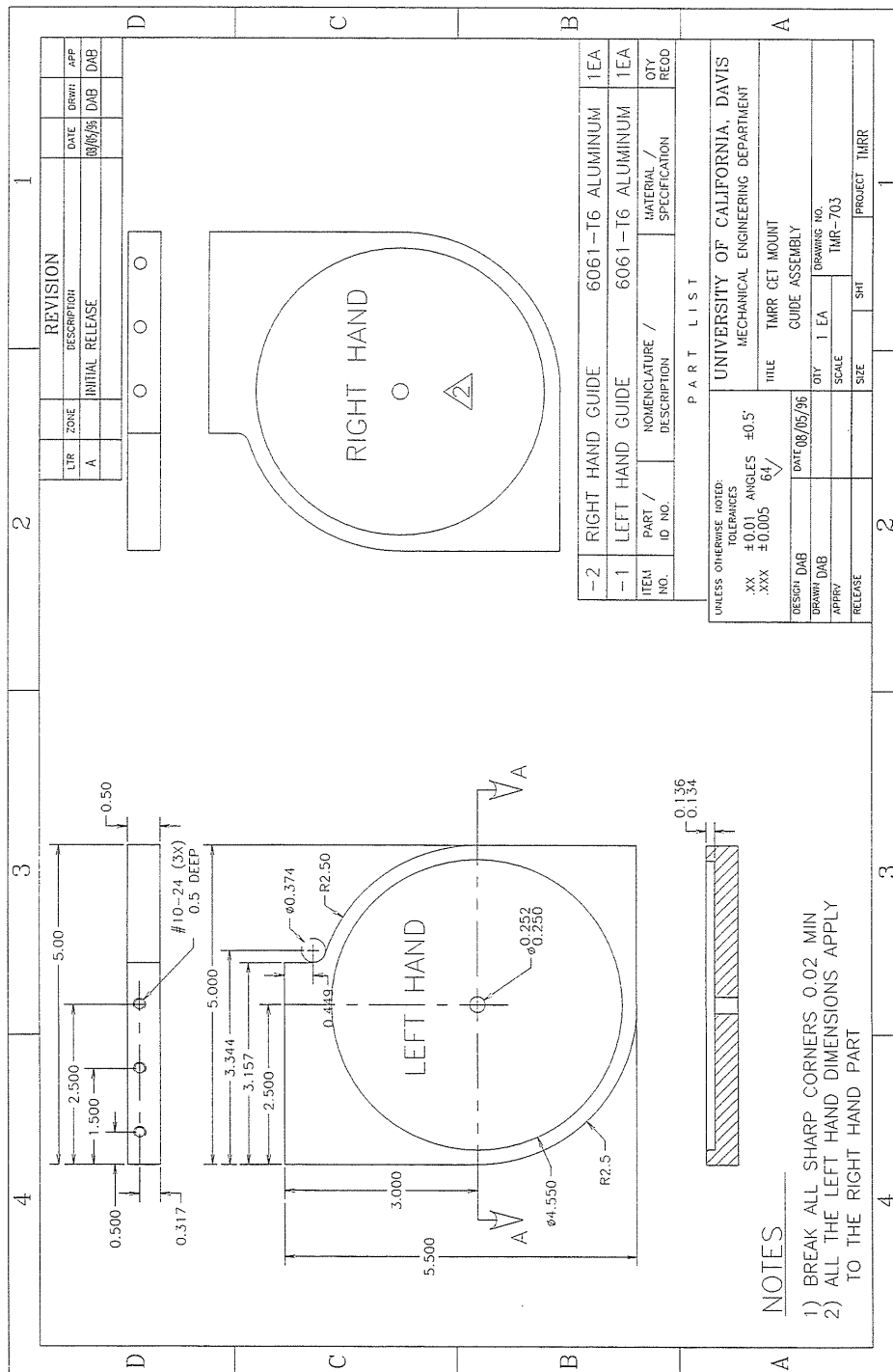


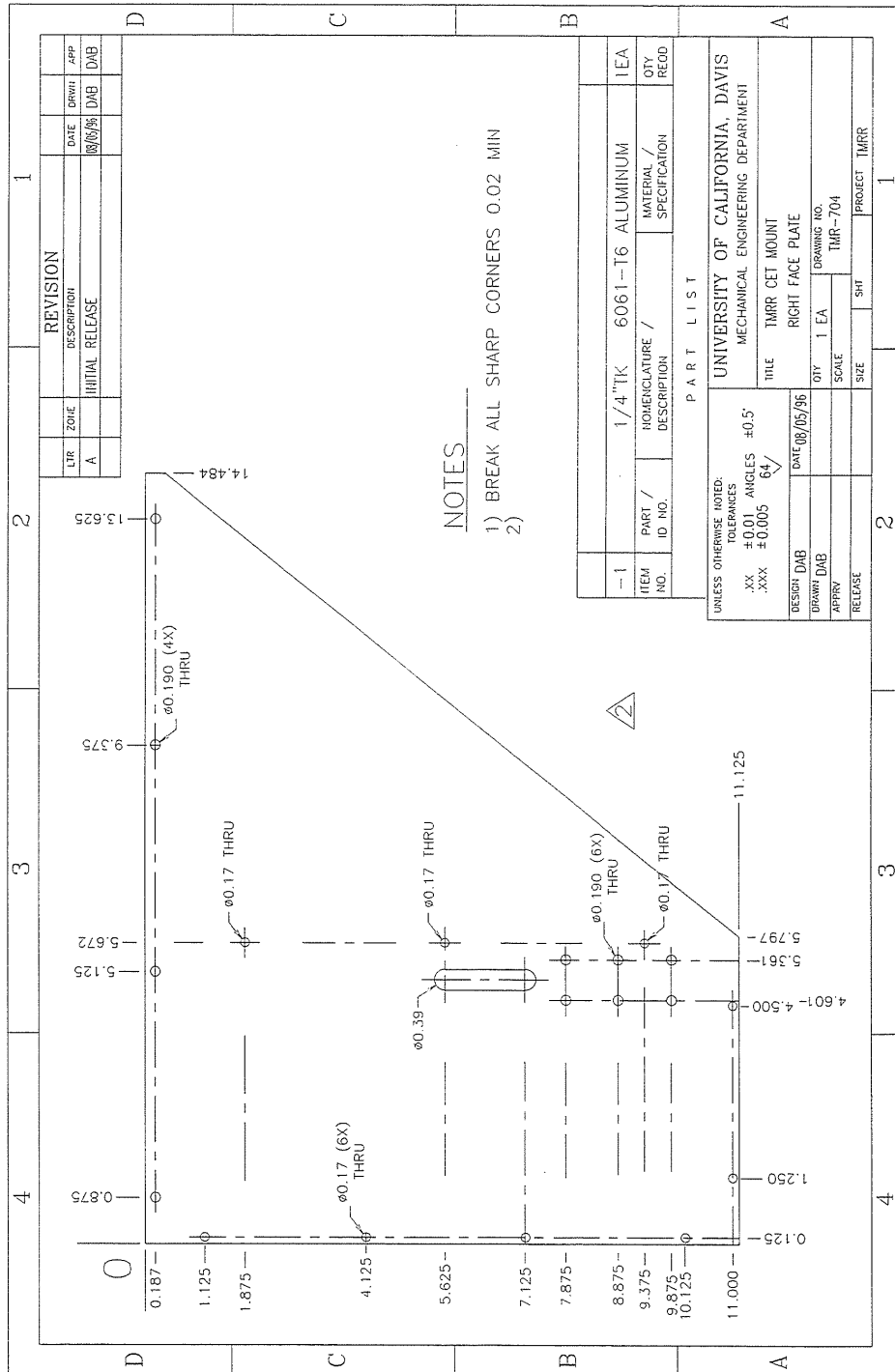


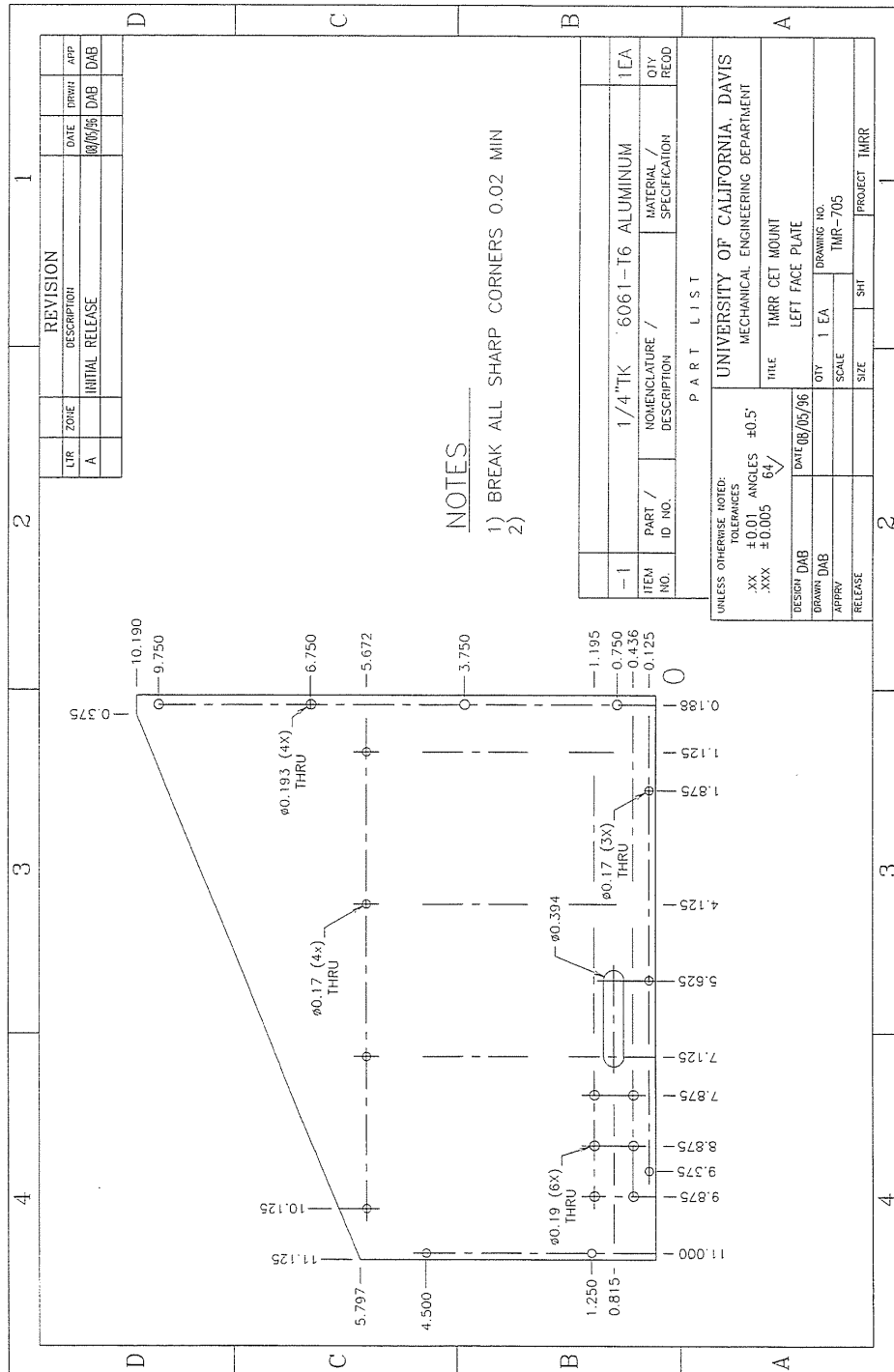


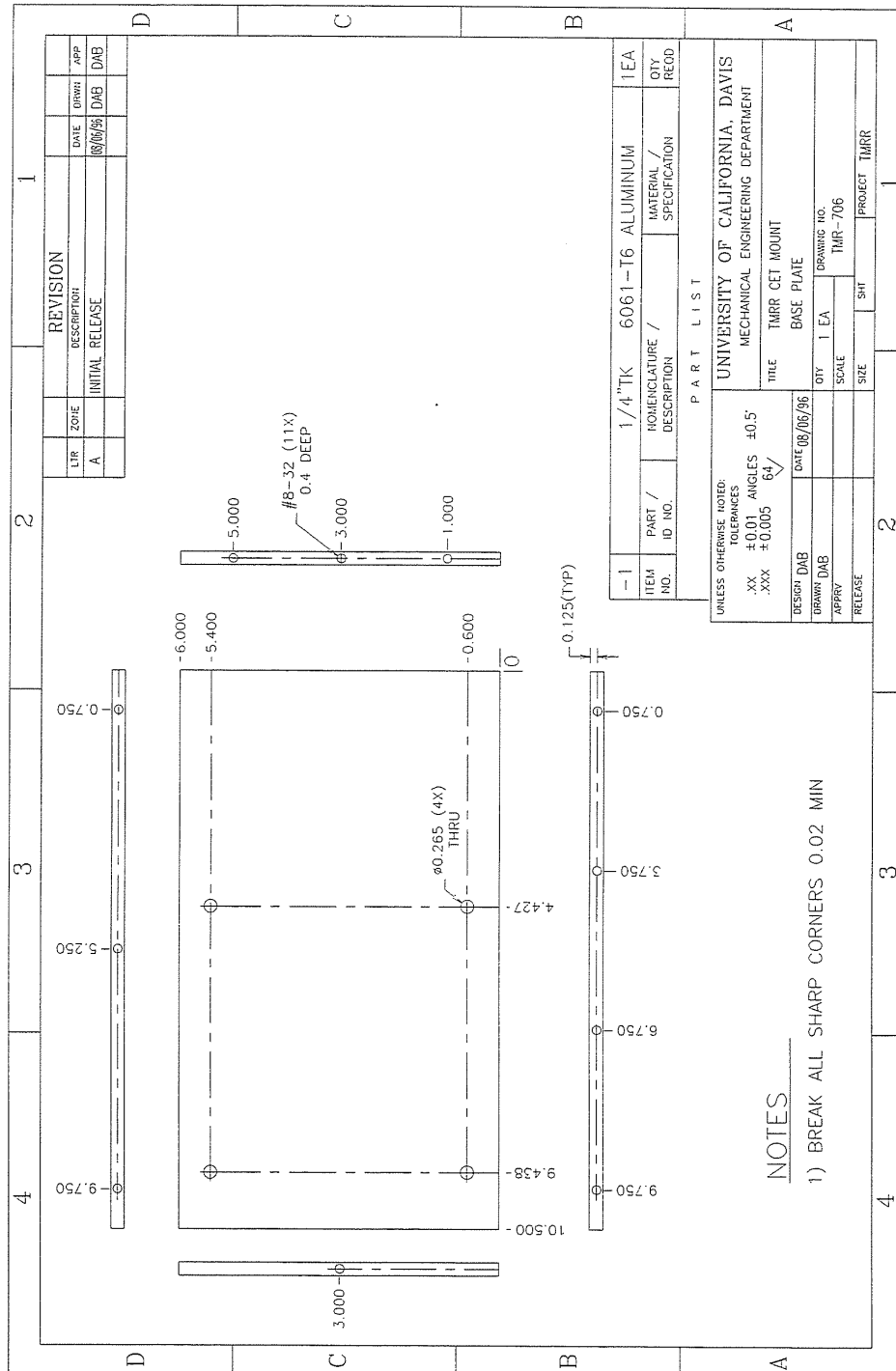


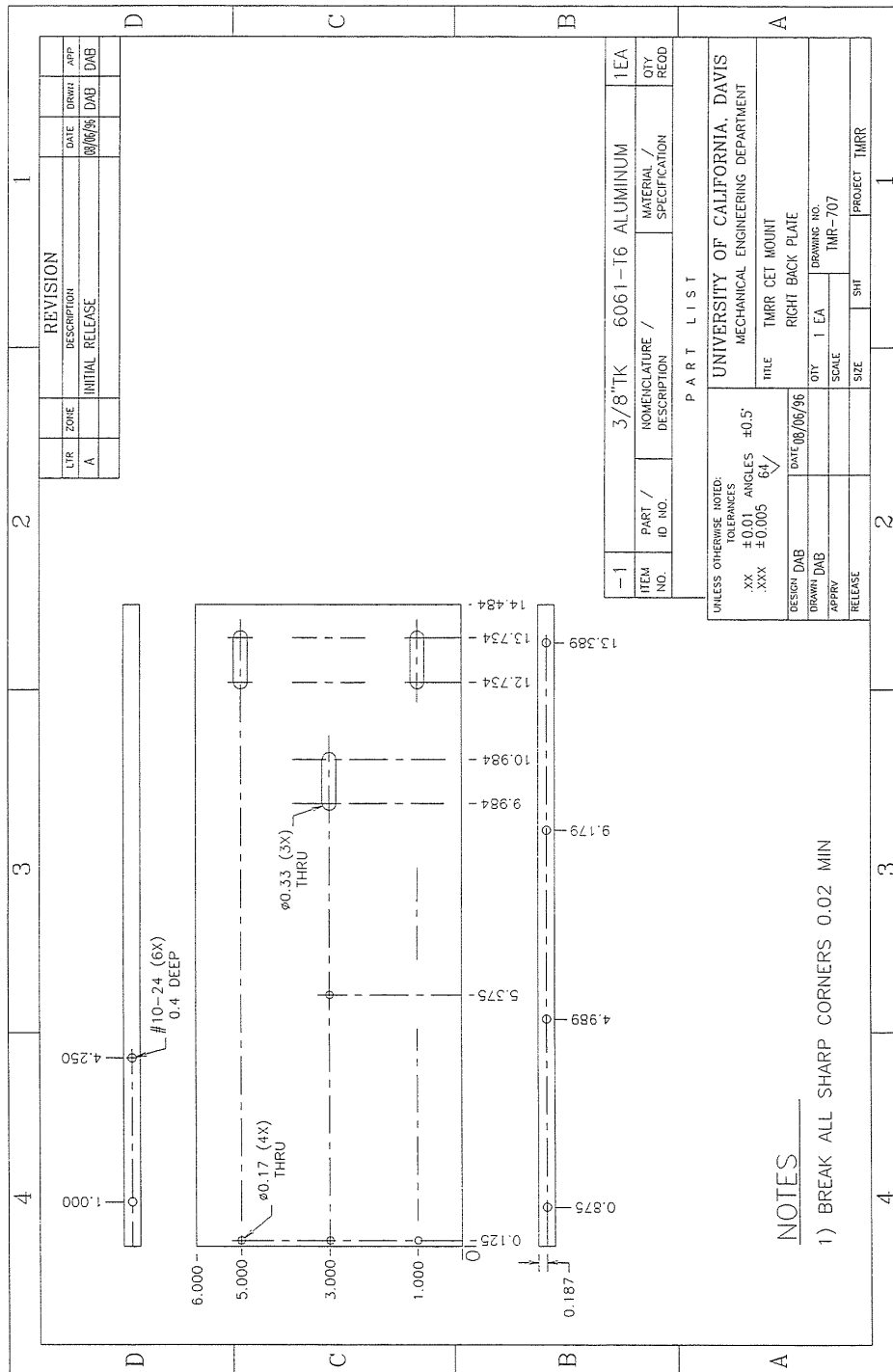




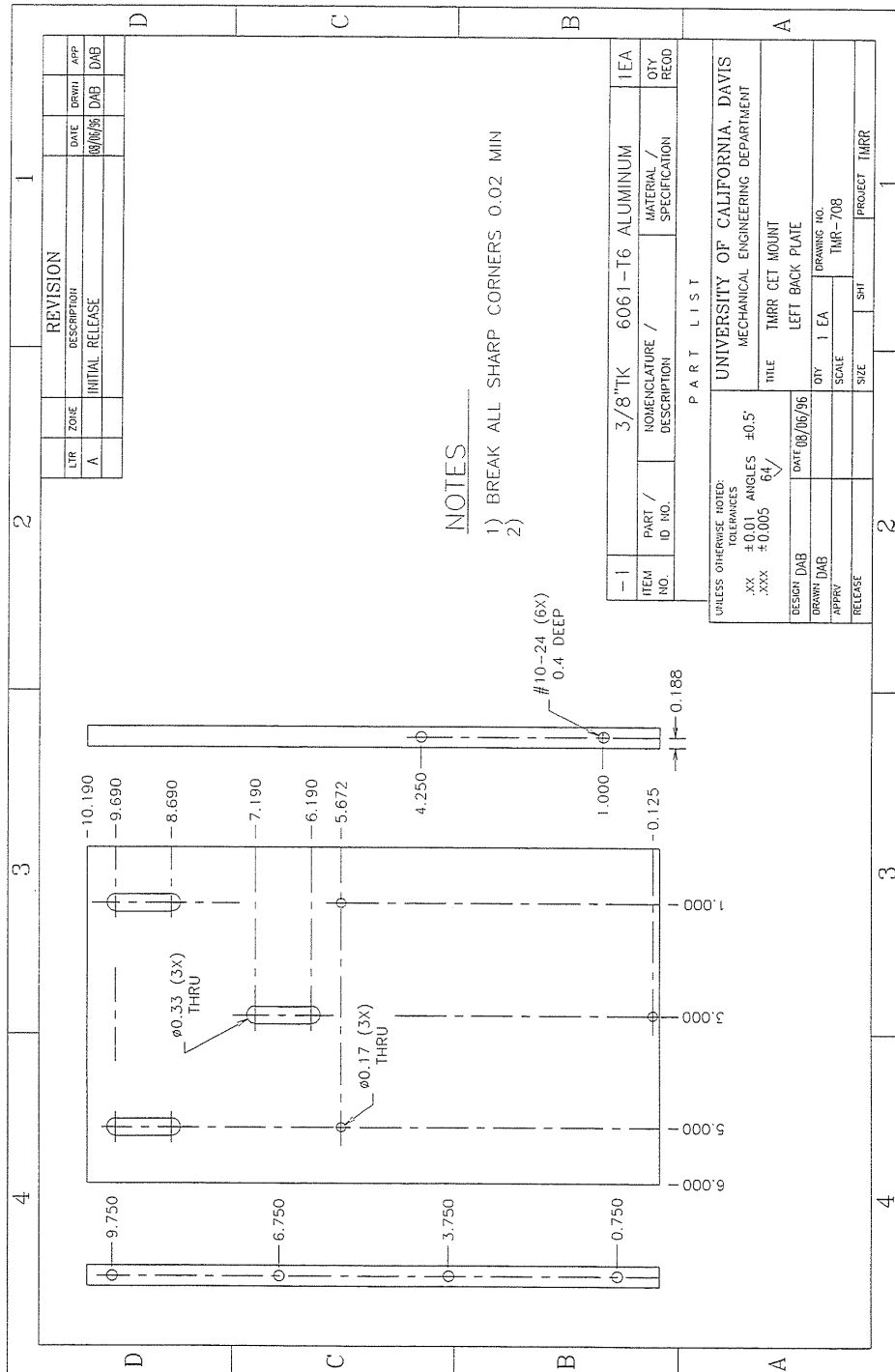


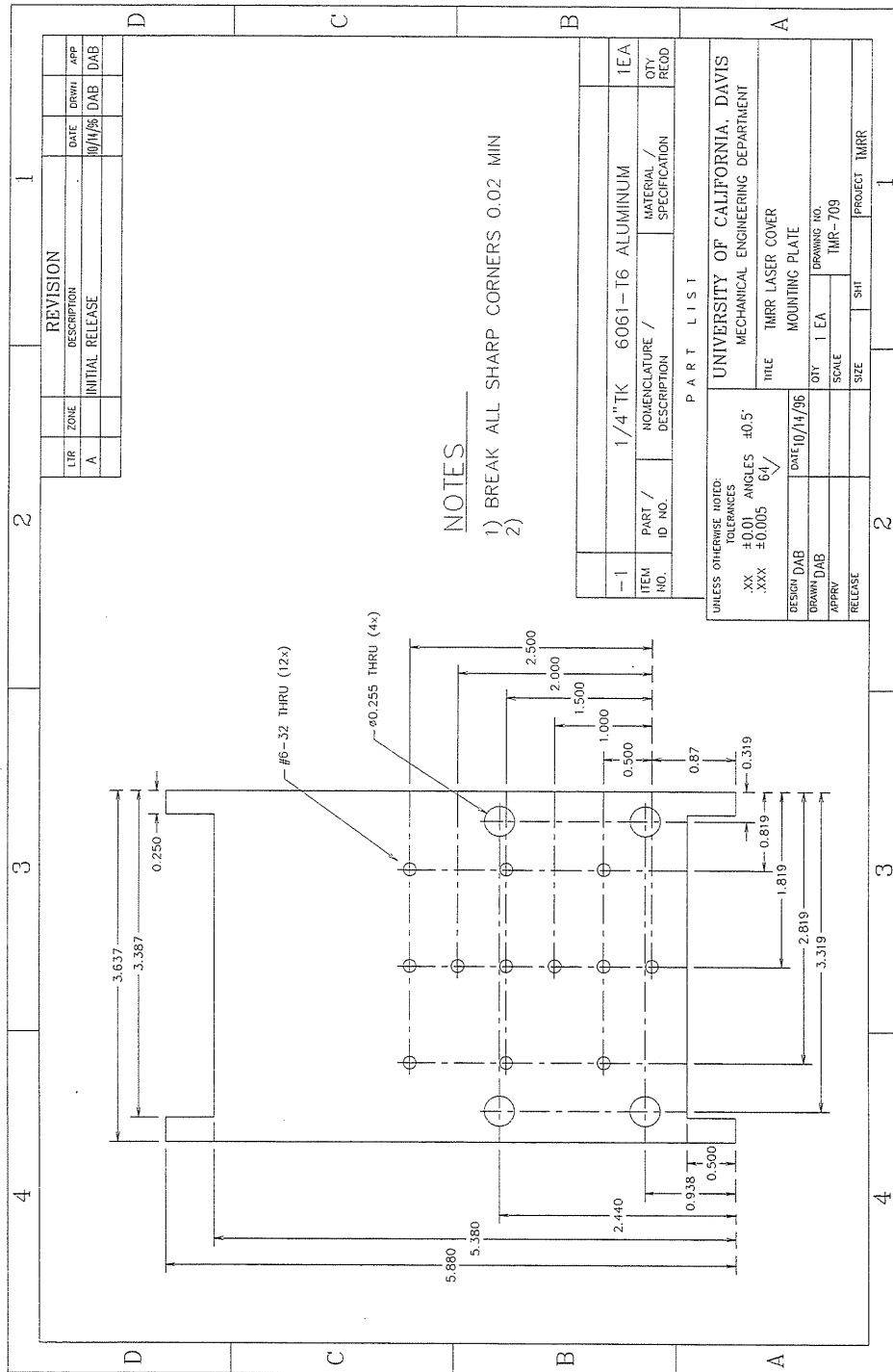


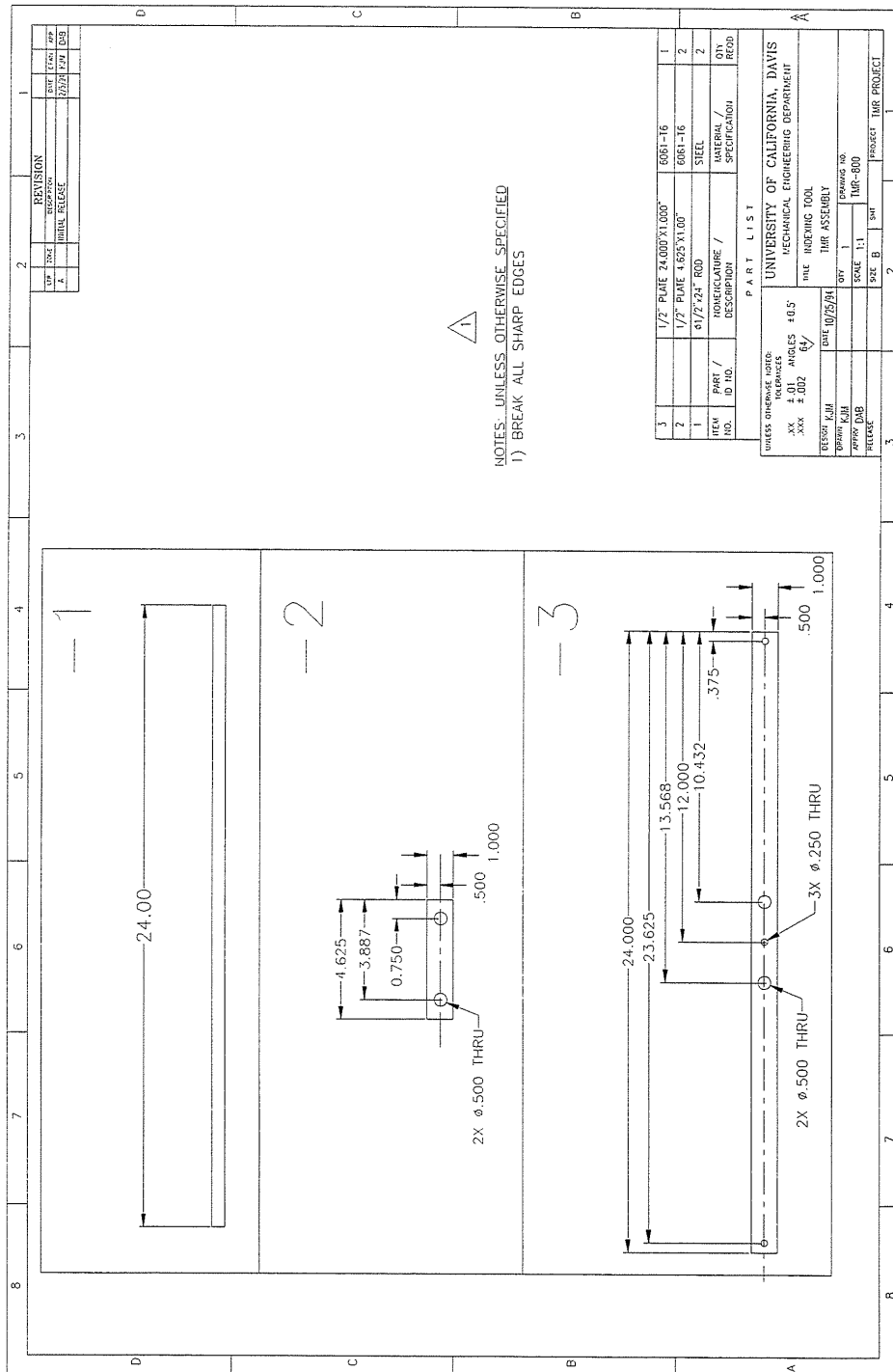




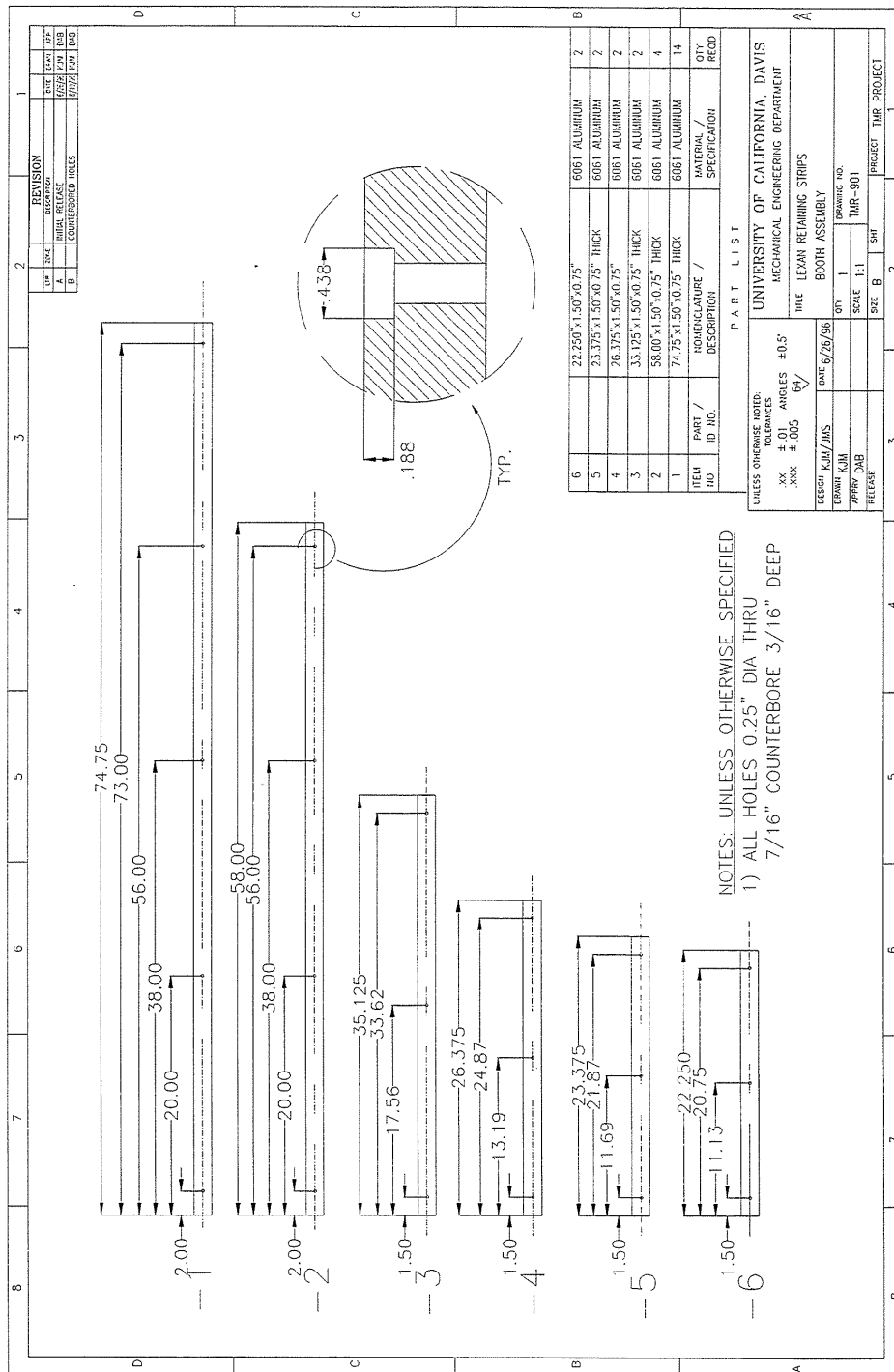


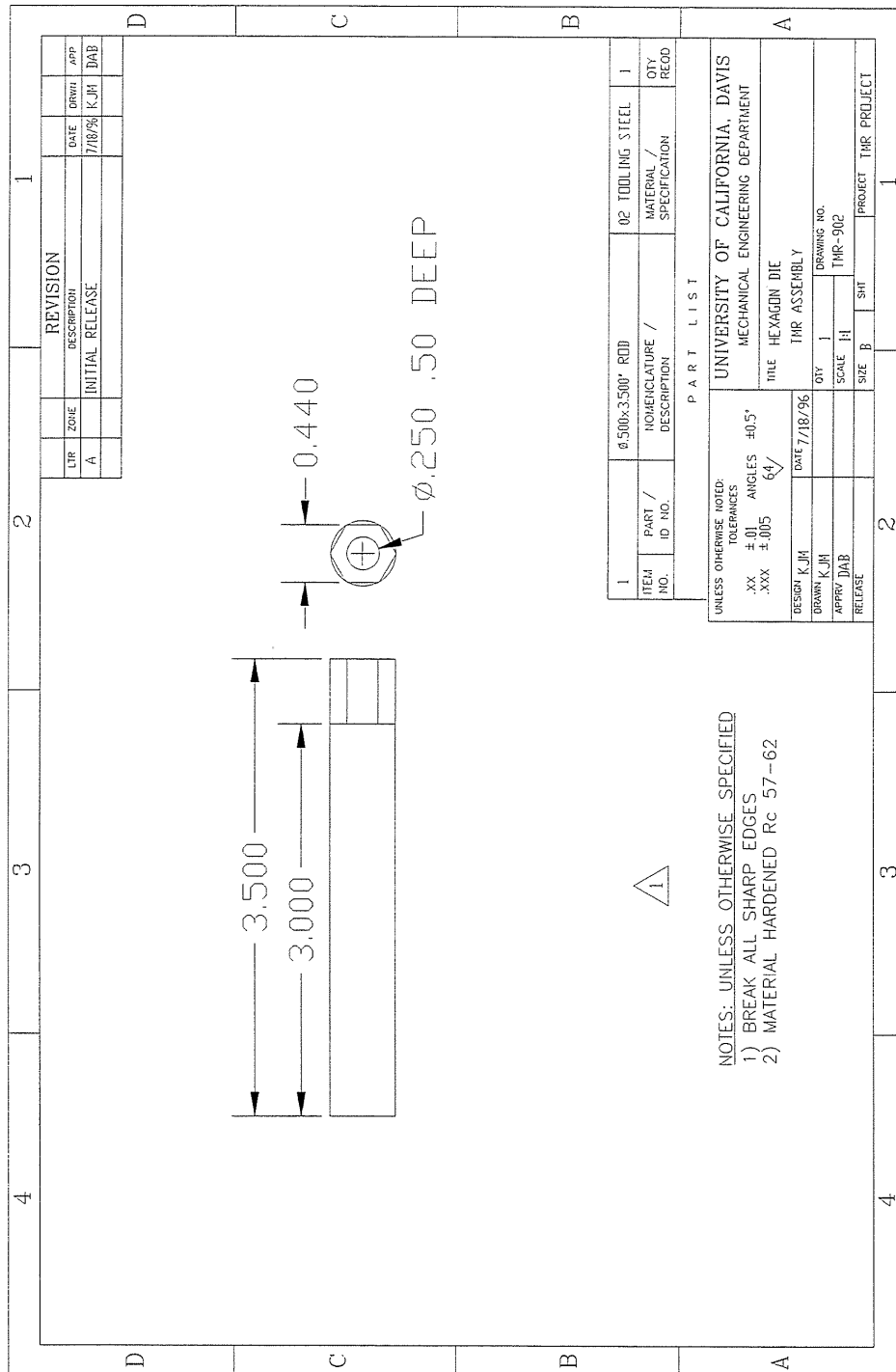












## APPENDIX D

### MANUFACTURERS' SPECIFICATIONS

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# Chapter 1: Introduction

## General

---

The SB586P(V) series CPU board is a full featured, industrialized, single board computer supporting the Intel® Pentium™ processor. It combines many of the features normally needed for system operation (high speed serial ports, parallel port, disk controllers) on one board. This reduces the number of slots required on the passive backplane, allowing room for additional feature cards. All of the onboard controllers may be totally disabled through the system BIOS if desired.

The CPU board uses the Peripheral Component Interconnect (PCI) bus to communicate with the onboard features. The external bus architecture complies with the Industrial Standard Architecture (ISA) with a PCI bus extension. The PCI bus extension supports the DEC bridge chip, allowing additional peripherals on the PCI bus.

A full range of Pentium processors with speeds ranging from 75MHz to 133MHz are supported on the SB586P(V) board. The processor is installed in a Low Insertion Force (LIF) socket and includes a heat sink to dissipate the excess heat it may generate. In environments exceeding +40°C, a fan cooled heat sink is recommended.

The board has four SIMM sockets, arranged in two banks, and will accept up to 192MB of RAM using 36 bit SIMMs. A 256k or 512k onboard cache option is available and is upgraded with plug-in Cache Modules.

## On-Board Controllers

---

On-board controllers are incorporated into the design of the SB586P(V) series CPU for disk drives, serial and parallel ports, and video except on the SB586P models. All on-board controllers are individually enabled or disabled with the system BIOS.

### Display

The SB586PV contains a SVGA controller which offers 1MB of DRAM and is upgradable to 2MB. The SVGA controller offers resolutions of up to 1280 x 1024 with 256 colors. The display portion includes a VESA feature connector, allowing other peripherals to share signals and control of the VGA circuitry. The PV Series Display Drivers and Utilities set is included with the CPU board and offers programs for display enhancements: Disk 1 is for DOS; Disk 2 and 3 are for Windows 3.1 and OS/2 2.1; Disk four is for OS/2 2.1X through 3.0. Please refer to Appendix B for further information on the video drivers. A video controller is not included on the SB586P series CPU.

| Resolution  | 1 Meg | 2 Meg |
|-------------|-------|-------|
| 640 x 480   | 16M   | 16M   |
| 800 x 600   | 64k   | 16M   |
| 1024 x 768  | 256   | 64k   |
| 1280 x 1024 | N/A   | 256   |

**Table 1-1:** Video Resolutions and Colors



## Disk Drive

Disk controllers are provided for floppy disk drives and SCSI devices, and a drive interface is provided for IDE fixed disk drives. The IDE interface, located on the PCI local bus, supports two drives and includes LBA and PIO mode 3 support allowing up to 12MB/sec throughput speeds. The floppy drive controller also supports two drives, ranging in density from 360K to 2.88MB floppy drives.

The SCSI controller is a single-ended SCSI-2 Wide and Fast controller, and is Adaptec AHA 2940 compatible. The bus width is jumper selectable as 8 bit or 16 bit to maintain maximum compatibility. With the 16 bit bus width selected (Wide SCSI), throughputs of up to 20MB/sec are possible.

Connection to the SCSI controller is provided through a Single-Ended, 68 pin "P" connector. The included SCSI cable allows for full use of 16 bit wide bus transfers. A 68 pin to 50 pin adapter is available to channel the SCSI bus signals to the standard 8 bit, 50 pin connection for older SCSI peripherals.

Normal SCSI and SCSI Wide devices may be used on the same SCSI bus via an optional adapter. If this is done, it is recommended to **have a terminated SCSI Wide Device at the end of the cable** to insure proper termination of all SCSI signals.

Please see the SCSI Connection section in Chapter 2 for further information.

## I/O Ports

Two serial ports compatible with the 16550 UART are available on the SB586P(V) CPU. The serial ports are extended through 10 pin headers on the board to bracket mounted DB-9 connectors. Also included is an Enhanced parallel port, capable of Bi-directional communication. The parallel port is accessible through the DB-25 connector on the rear bracket of the CPU board.

## Watch Dog Circuit

---

The watch dog circuit is a hardware timer that resets the CPU if the timer is not refreshed periodically. The circuit is refreshed by a trigger pulse provided by the BALE bus line. Any event, such as a read or write to memory, disk drive activity, video refresh, etc., will trigger the BALE line and thus reset the timer. If the processor should become hung-up, the watch dog circuit will time out and reset the CPU. The watchdog circuit is set to reset the CPU if it is not refreshed for 150msec or greater. Also, a power monitor, built into the same circuit, is set to reset the CPU if the +5VDC power varies by more than 5%.

## Specifications

---

### Processors Supported

Intel Pentium in a LIF (Light Insertion Force) Socket

### Processor Clock Rate

75MHz, 90MHz, 100MHz, 120MHz, or 133MHz

### Chip Set

Neptune II

### BIOS

Hi-Flex Pentium AMIBIOS, Flash EPROM Support

### ISA Bus Clock Rate

8.33Mhz

### PCI Bus Clock Rate

25Mhz, 30Mhz, or 33Mhz

### Memory Capacity

192MB Maximum On-board

### SIMM Support

2 Banks, 2 Sockets each, 72-Pin

Supports 256k x 36(1MB), 1M x 36(4MB), 2M x 36(8MB), 4M x 36(16MB),  
8M x 36(32MB), and 16M x 36(64M) SIMMs.

**Note:** Only Bank 0 supports 16M x 36 SIMMs.

### Memory Speed Required

70ns or faster

### Video Controller - SB586PV

SVGA Video

1MB DRAM installed, Sockets for additional 1MB DRAM

VESA Feature Connector

Driver Support under supported operating systems

Rear Panel DB-9, High Density, 15 pin connector, female

### Cache Memory

16kB Internal Pentium Chip Cache

256kB or 512kB Cache Options, plug in modules

**IDE Disk Controller**

2 Fixed Disk Drives Supported on the PCI Local Bus  
Secondary Controller Support  
LBA and PIO Mode 3 Support

**SCSI Disk Controller**

SCSI-2 Fast, Wide controller, Located on PCI Local Bus  
8-bit or 16-bit bus, Jumper Selectable  
To 20MB/sec Throughput  
Adaptec AIC-7870 Single-Chip Host Adapter

**Floppy Controller**

2 Floppy Drives, up to 2.88MB Supported

**Serial Ports**

2, RS232, 16550 Compatible, FIFO Buffer  
Isolated to  $\pm 1500V$  ESD  
MAX211E Component incorporated for enhanced ESD protection

**Parallel Port**

1, Centronics Compatible, Bi-directional Compatibility  
EPP and ECP Enhanced Port Modes

**Keyboard, Speaker, & Reset Port**

Single 8 pin Header Connector for System Interface

**Note:** The keyboard may be selected as *absent* or *present* by the system BIOS. This will allow the system to boot without a keyboard attached.

**Watchdog Timer**

Reset CPU automatically if CPU stops operating  
Reset CPU automatically if +5VDC varies more than 5%

**CMOS Battery**

On-board, Included

**Supported Operating Systems**

Windows NT<sub>TM</sub> V3.1 and later  
Windows '95<sub>TM</sub>  
SCO Unix<sub>TM</sub>  
MS-DOS<sub>TM</sub>  
Windows 3.11<sub>TM</sub>  
QNX<sub>TM</sub>  
OS/2<sub>TM</sub> V2.0 and later

**Operating Environment**

Temperature: -10°C to +55°C

Humidity: 5% to 95% RHNC

Shock: 5G, Any Axis

Vibration: .5G, 10-500Hz, Any Axis

Altitude: 0 to 10,000ft

**Storage Environment**

Temperature: -40°C to +85°C

Humidity: 5% to 95% RHNC

Shock: 10G, Any Axis

Vibration: 1G, Any Axis

**MTBF**

Calculated with Mil-Hndbk-217e

>92,500 P.O.H. @ 25°C

**Power Requirements**

+5V @ 2.8A Typical, No DRAM or Cache

+12V @ <100mA Typical

-12V @ <100mA Typical

**Compatibility Testing**

XXCAL Labs Gold Certification

## CyDAS™ 8JR Multifunction A/D Boards from \$99!

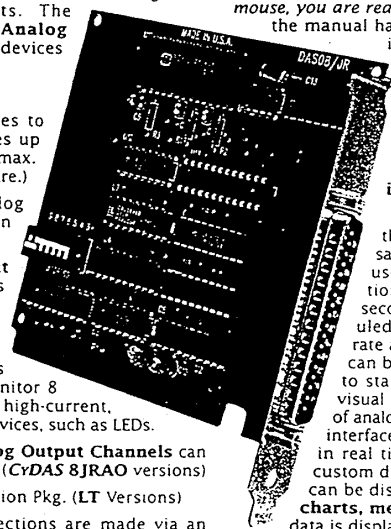
### The Lowest-Cost Solution for Data Acquisition

The **CyDAS 8JR Series** of multifunction analog and digital I/O boards plug directly into a PC expansion slot. They're designed specifically for educational & high-volume OEM applications where cost is the primary consideration. With Labtech NOTEBOOK software, you get a **complete data acquisition solution for only \$199!**

The **CyDAS 8JR** is ideal for low-speed (up to 20kHz) data acquisition applications with signals in the  $\pm 5V$  range, such as: test and measurement, process control, transducer monitoring, data collection, and laboratory experiments. The **CyDAS 8JRAO**, with **2 channels of Analog Output (D/A)**, can be used to control devices such as proportional valves.

**CyDAS 8JR Series boards feature:**

- **12-bit A/D converter** which resolves to 2.4mV steps. Sustained Sample Rates up to **20,000/sec.** (1,000 samples/sec. max. using bundled ver. of NOTEBOOK software.)
- **8 Channels of Single Ended Analog Input (A/D)** with overvoltage protection to  $\pm 30V$  max., continuous.
- Analog Inputs have a **fixed  $\pm 5V$  input range.** A 2 $\mu$ sec sample & hold captures the signal for the A/D converter. Acquisition/transfer cycles can only be triggered via a software command.
- **16 bits of Digital I/O**, 8 out/8 inputs can control 8 discrete devices, & monitor 8 contact closures. Digital outputs are high-current, able to sink 24mA to drive electronic devices, such as LEDs.
- **Option: 2 Independent 12-bit Analog Output Channels** can output voltage at  $\pm 5V$ , in 2.4mV steps. (CyDAS 8JRAO versions)
- **Option: LABTECH NOTEBOOK Solution Pkg. (LT Versions)**
- All the analog and digital I/O connections are made via an industry-standard 37-pin "D-type" connector at the rear of the PC. A selection of matching, economically-priced terminal boards and interface cables is available starting on page 124.



### CYDAS 8JR + LABTECH NOTEBOOK™ = Solution Package

CyberResearch has developed a new Solution Package which includes the **CyDAS 8JR** with a Special Version of the powerful **LABTECH NOTEBOOK** software package for DOS or Windows, complete with all necessary drivers for the CyDAS 8JR. **This is the full \$495 version of LABTECH NOTEBOOK**, with limited speed capability, and drivers for use with the CyDAS 8JR series only.

The **CyDAS 8JRLT solution package converts your PC into a powerful data acquisition system.** With just 2 clicks of the mouse, you are ready to collect data. The product is so simple that the manual has been replaced by extensive on-line help. Yet it maintains the powerful features that have made NOTEBOOK such a popular program for data acquisition and control. You can collect, analyze, display, & store data, plus monitor and control physical variables such as force, pressure, temperature, flow, and transducer outputs. Setups are fast and easy with NOTEBOOK's **iconic graphical interface** and **Windows' On-Line Help.**

Flexible process monitoring capabilities allow the user to configure applications with a variety of sampling rates and sensor types. Simple menus are used to initiate data logging, and real-time calculations. Sampling rates from a thousand points per second (max) to a few points per day may be scheduled, with each I/O point having its own sampling rate and triggering conditions. **Software triggering** can be set on an analog, digital, or calculated value, to start or stop monitoring of an I/O point, or offer visual instructions to the operator. For accurate control of analog devices, **PID control is included.** The operator interface graphically displays data and controls processes in real time. Users can quickly design and implement custom displays using the **Windows Icon tool-bar.** Data can be displayed in a number of formats, including **strip charts, meters, and bar charts.** You can change the way data is displayed while it is being acquired. **Users can create knobs, dials, slide bars, and buttons;** and use the powerful drawing and animation tools to customize displays which can be **animated** to best demonstrate what is happening in real time.

### 1.1 SUMMARY OF DDA-06 FUNCTIONS

The DDA-06 is an analog/digital I/O expansion board for the IBM Personal Computer<sup>1</sup> providing 6 channels of 12-bit analog output and 24 lines of digital I/O. The following functions are implemented on the DDA-06:

1. 6 independent 12-bit D/A converters are provided. Each is individually switch and jumper selectable to any of the following ranges:

- 0 to +10 V
- 0 to +5 V
- 2.5 V to +2.5 V
- 5 V to +5 V
- 10 V to +10 V
- 4-20 mA current loop (sink)

Each D/A has a double buffered input for single step update and occupies its own I/O location. By means of jumper blocks, it is possible to select any or all of the D/As to update simultaneously. Since each D/A output uses one pin of the rear 37-pin D-type connector, D/As may be operated in either voltage output mode or current output (but not both together). In voltage mode, output settling time is typically 3 microseconds to 0.01% for a full-scale step.

2. 24 bits of digital I/O are provided on the rear connector consisting of 3 ports of 8 bits. Each port may be independently programmed as an input or output and is TTL/CMOS compatible. An 8255 programmable peripheral interface chip is used for digital I/O and can be operated in any of the 8255 modes 0-2 (straight I/O, strobed I/O, and bidirectional I/O).

The following utility software is included with the DDA-06 on a single sided PC DOS 1.10 format 5 1/4-inch floppy disk (compatible with DOS 2.0/2.1/3.0 etc.):

- 1) DDA06.EXE/.BAS - A comprehensive installation, switch setting, calibration, and test program.
- 2) EX.BAS - A "mergeable" BASIC D/A driver subroutine.

---

1. Registered trademark of International Business Machines Corporation.

A system block diagram appears in Fig. 1-1. To extend the capabilities of the DDA-06, the following expansion modules can be connected via flat insulation displacement cable to the main 37-pin D-type connector:

- 1) SCREW TERMINAL CONNECTOR BOARD - The STA-U universal screw connector board can be used for making screwdriver connections to all the I/O functions. The STA-U also provides a "daisy-chain" socket for connection to further accessories, e.g. ERB-24 relay board.
- 2) ERB-24 ELECTROMECHANICAL RELAY BOARD - This board provides 24 D.P.D.T. (double pole changeover) relays, each driven by one of the DDA-06 digital I/O lines. It is directly plug compatible with the DDA-06.

# 1 Introduction and Installation

## 1.1 Description

The Model 5312B Quadrature Encoder Input card is PC Bus compatible. It provides inputs and decoding for up to four incremental quadrature encoders depending on the model purchased. The card also may be used as a high-speed pulse counter (up/down and pulse/direction) for general counting applications. Figure 1.1 shows a functional block diagram.

**NOTE:** This manual is model independent. For models not utilizing all encoder ports, disregard the appropriate upper axes.

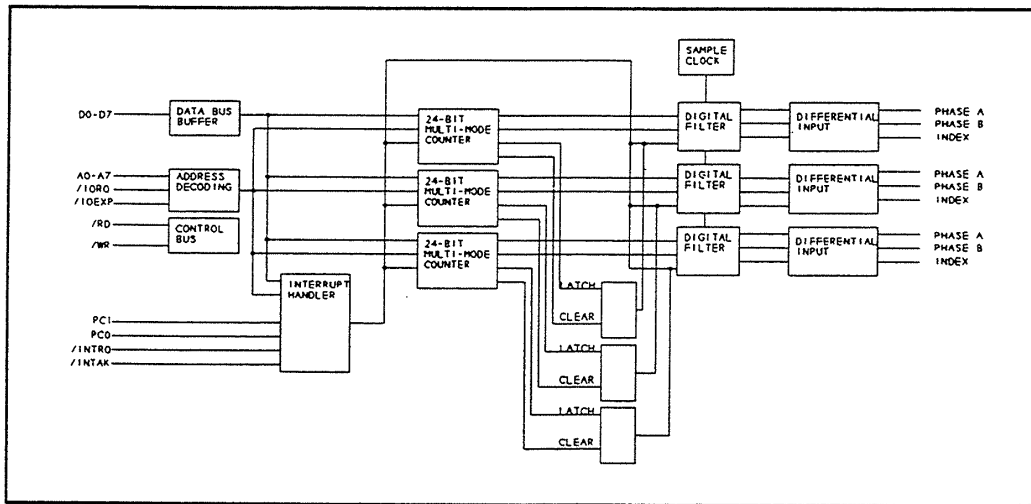


Figure 1.1 Functional block diagram for the 5312

For each encoder circuit, Phase A (Phase 0), Phase B (Phase 90), and Index pulse inputs are provided. Jumper options on the board allow inputs to be configured as single-ended TTL or differential (the recommended connection method). Individual connectors for each encoder provide power (+5V) and ground for the encoder if needed.



The Model 5312B may also be used as an event (pulse) counter. Four independent events may be counted, or the counters may be cascaded to provide high speed pulse counting over an extended count range.

Inputs are conditioned by a four-stage digital filter. The filter clock is one of five jumper-selectable sampling frequencies ranging up to 10 MHz. Selecting the lowest frequency compatible with the highest expected input rate will maximize noise immunity. The maximum input rate per phase in Quadrature Decode Mode is approximately 333 kHz. The maximum input rate in the Count Mode is approximately 1.25 MHz. Sample clock frequency selection is described in detail in section 2.

The conditioned inputs are applied to a 24-bit counter provided for each encoder. The counters may be used for quadrature decoding, pulse and direction input counting, or as a pulse input up/down counter. Count output is available for the PC Bus in binary or binary coded decimal (BCD) form. The count value may be latched on command, latched on an index pulse, or latched with a new count value when an index pulse occurs.

The Model 5312B is capable of generating interrupts. Maskable interrupts may come from a valid index pulse, counter overflow/underflow, or on count value match with a preset compare value.

## 1.2 Technical Specifications

### • Voltage Requirements

- PC Bus: 5 Volts at:

|        |                 |                 |
|--------|-----------------|-----------------|
| 4-axis | 1.5A (typical)  | 2.0A (maximum)  |
| 3-axis | 1.25A (typical) | 1.75A (maximum) |
| 2-axis | 1.0A (typical)  | 1.5A (maximum)  |
| 1-axis | 0.9A (typical)  | 1.25A (maximum) |

### • Compatibility

- PC/XT/AT
- Single-ended or Differential
- Incremental Encoders
- TTL or CMOS Signal Sources

### • Operating Range: 0 to 70 degrees Celsius

### • Mating Connectors

- 9-pin D-sub
- Ansley 609-9p
- Amphenol 841-17-DEFR-B09P

### • Card Dimensions: 13.3 x 4.2 x 0.5 inches



# PC7166 PC to Incremental Encoder Interface Card

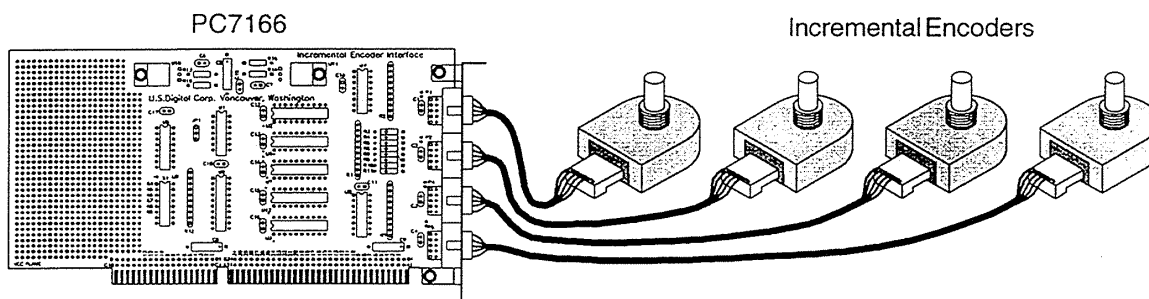
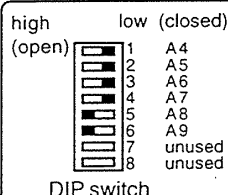
Technical Data, Rev. 05.09.96, May 1996

The PC7166 daughter board plugs into a standard 8 or 16 bit ISA slot of IBM PC compatible computers. It includes four LS7166 24-bit quadrature counters and accepts single ended TTL signals or RS422 differential quadrature inputs. This card also provides 5V power to the encoders.

Software with source code in C for DOS, Windows 3.1, and Windows 95/NT is included. The software displays the position of each encoder and allows the user to change the parameters of the PC7166. This is a good starting point for the development of your custom software.

## Features

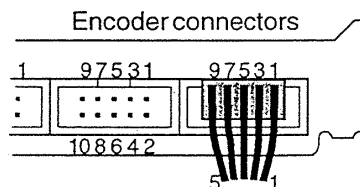
- 4 channels
- Preloadable up/down 24 bit counters
- Latched counter outputs
- X1, X2, X4 resolution multiplier
- TTL and RS422 differential interface
- Interfaces to S1, S2, E2 encoders and T2 inclinometers
- Demo software
- Prototyping area on board



The PC7166 card uses 16 consecutive IO addresses. The location is determined by the setting of addresses A4 to A9 on the DIP switch. This address block must not be used by other devices on the bus. Probable choices are: 220, 240, 250, 260, 300, 310, 330, 340, 350, 360 hex (factory default is 300).

When using a 5 pin connector in place of a 10-pin connector, use the upper row (pin 1 to pin 1).

The connector should be centered and well seated.



## Functional pin description

| Pin  | Name | Description                                              |
|------|------|----------------------------------------------------------|
| 1    | GND  | Ground, common for power and data.                       |
| 2    | GND  | Ground, common for power and data.                       |
| 3, 4 |      | No connection                                            |
| 5    | A-   | Quadrature input, differential or TTL, see note 1.       |
| 6    | A+   | Quadrature input, differential only, see note 1.         |
| 7    | PWR  | Power supply output to encoder (190 mA max per encoder). |
| 8    | PWR  | Power supply output to encoder (190 mA max per encoder). |
| 9    | B-   | Quadrature input, differential or TTL, see note 1.       |
| 10   | B+   | Quadrature input, differential only, see note 1.         |

## Part Number:

PC7166

## PC7166 Price:

\$155 / 100  
\$205 / 10  
\$225 / 2  
\$250 / 1

## Absolute maximum ratings

| Parameter                 | Min. | Max. | Units |
|---------------------------|------|------|-------|
| Storage temperature       | -40  | 100  | °C    |
| Operating temperature     | 0    | 70   | °C    |
| Humidity (non-condensing) | 0    | 95   | %     |

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**DC Electrical Characteristics**

Over operating temperature range. Typical values are specified at 25°C

| Parameter                                        | Min          | Typ. | Max.       | Units | Notes                                 |
|--------------------------------------------------|--------------|------|------------|-------|---------------------------------------|
| +5V input current (from ISA bus)                 |              |      | 310        | mA    | independent of load                   |
| +12V input current (from ISA bus)                |              |      | 80         | mA    | no load. See note 1                   |
| Output voltage PWR (to encoders)                 | 5.00         | 5.25 | 5.50       | Volts | See note 1                            |
| Output current (per encoder)                     |              |      | 190        | mA    | See note 1                            |
| Differential input voltage<br>IA+ - A-, IB+ - B- | 0.2          |      | 14         | Volts | See note 2                            |
| Common mode input voltage<br>(A+A+)/2, (B+B+)/2  | -7           |      | 12         | Volts | See note 2                            |
| Input current (Vin = 0 to 5V) A-, B-<br>A+, B+   | -0.4<br>-2.7 |      | 2.7<br>2.7 | mA    | no termination<br>resistors installed |
| Single ended input voltage low<br>A-, B-         |              |      | 1.8        | Volts | See note 2                            |
| Single ended input voltage high<br>A-, B-        | 3.2          |      |            | Volts | See note 2                            |
| Count frequency                                  | 0            |      | 10         | MHz   |                                       |

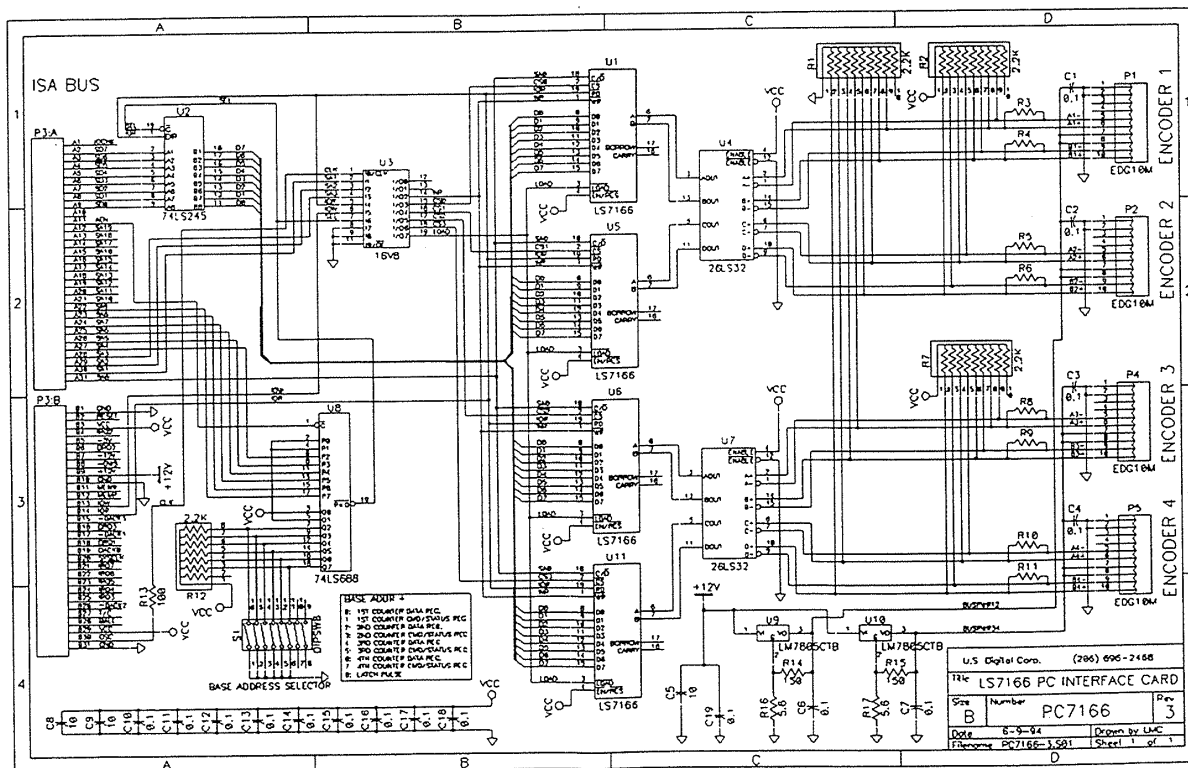
**Notes:**

1) The power output (PWR) to the encoders is +5.25V regulated from the +12V supply of the ISA bus. Therefore the current drawn from the +12V supply is  $\leq 80\text{mA}$  plus current drawn by the encoders (and termination resistors, if installed). The power output to the encoders is protected against shorts, but a peak current of about 2.5A can occur for each encoder pair during a short. When using long cables, consider the voltage drop due to the current consumption of the encoder.

2) The quadrature inputs are setup to receive differential signals (RS422) or single ended TTL signals. When using the single ended interface, use A- (pin 5) and B- (pin 9). Those pins have a 2.2 k $\Omega$  pullup to +5V. The A+ and B+ pins have 2.2 k $\Omega$  resistors to +5V and to ground, effectively 1.1 k $\Omega$  to 2.5 V, to keep them at that level when they are not used.

3) When using the differential interface, termination resistors can be optionally installed in the socket provided (R3 & R4 for encoder 1, R5 & R6 for encoder 2, R8 & R9 for encoder 3, R10 & R11 for encoder 4). Those termination resistors must be removed if a single ended, TTL encoder is to be used. For twisted pair cables, the typical termination resistor value is 100  $\Omega$ .

4) Differential interface is recommended for noisy environments, cables longer than 6 feet, and high speed applications. The PC4 option can be added to our S1, S2, E2, E3, H1, H3 and T2 encoders to convert them to differential outputs.



All information subject to change without notice.

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# 1

## Overview

The PIO-32 Series boards are part of a family of digital input and output (I/O) boards for the IBM® PC/XT™ and PC AT® computers and compatibles. These boards provide a flexible interface for a variety of parallel I/O devices, including instruments, displays, and control systems.

The members of the PIO-32 Series are as follows:

- PIO-32I/O, which provides 16 digital inputs and 16 digital outputs
- PIO-32IN, which provides 32 digital inputs
- PIO-32OUT, which provides 32 digital outputs

The major features of all PIO-32 Series boards include the following:

- 300 V isolation, channel-to-channel and channel-to-computer
- Input level (if included) of 3.5 VDC to 28 VDC
- Output relay contacts (if included), Form A, 0.75 A at 200 VDC
- Connections through on-board ribbon headers
- High-density channel count
- Only one slot required for the board

1-1

# 2

## Functional Description

This chapter describes the general layout of the PIO-32 Series boards and provides schematics of the typical input and output circuits.

The PIO-32 Series boards are channel-to-channel isolated and handle digital voltages in a broader range than standard TTL levels. Optional accessories for the board include screw terminal panels (STPs) and the C-3200 cables. The C-3200 cables are 30-inches long; they let you route the signals from 40-pin headers on the board through a slot in the rear panel bracket to 37-D male connectors. You connect the 37-D connectors to the optional STPs.

Figure 2-1 shows the general layout of PIO-32 Series boards. Note the ribbon headers, labeled J1 and/or J2, on your board; these ribbon headers provide 16 digital input or output channels each. The orientation of the headers differs among the boards, as shown in Figure 2-1.

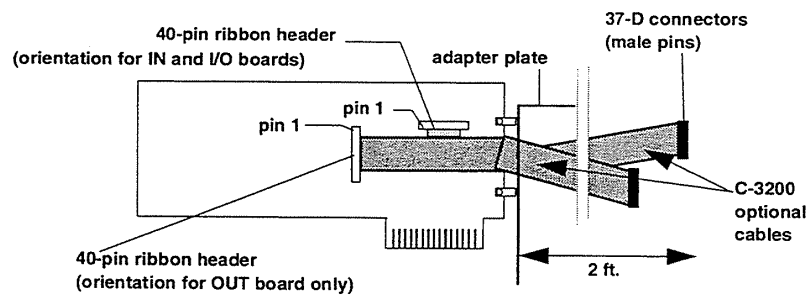


Figure 2-1. General Layout of PIO-32 Series Boards

2-1

## Input Circuitry

The PIO-32I/O has 16 digital input channels and uses the J1 ribbon header (channels 0 to 15). The PIO-32IN has 32 digital input channels and uses the J1 and J2 ribbon headers (channels 0 to 31). Each input channel is rated to 500 V of optical isolation; however, ribbon cables such as the C-3200 limit isolation to 300 V. Figure 2-2 shows each input channel schematically. Voltages greater than 28 VDC require external resistors. In addition, you must limit the input current to 15 mA maximum. The positive input signals are labeled PnP (where  $n$  is the bit number, 0 to 31); the negative input signals are labeled PnN (where  $n$  is the bit number, 0 to 31).

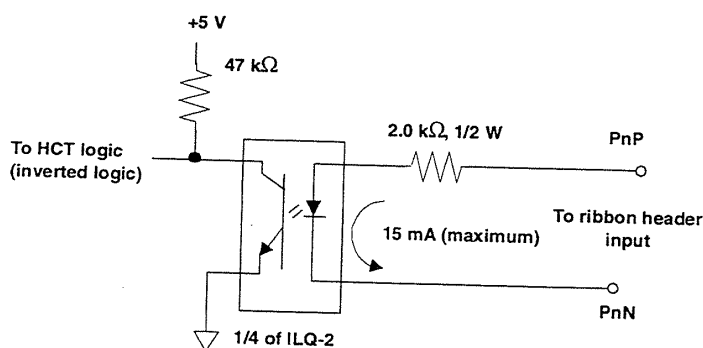


Figure 2-2. Typical Input Circuit

## Output Circuitry

The PIO-32I/O has 16 digital output channels and uses the J2 ribbon header (channels 16 to 31). The PIO-32OUT has 32 digital output channels and uses the J1 and J2 ribbon headers (channels 0 to 31). Figure 2-3 shows the output channels schematically. The output channels are reed relays (form A) rated to 10 W at 0.75 A or 200 VDC (resistive) and rated to 500 VDC isolation, with the exception that ribbon cables such as the C-3200 limit isolation to 300 VDC. The relay connections are not polarized (positive or negative equivalent) and are labeled PnP and PnN (where  $n$  is the bit number, 0 to 15).

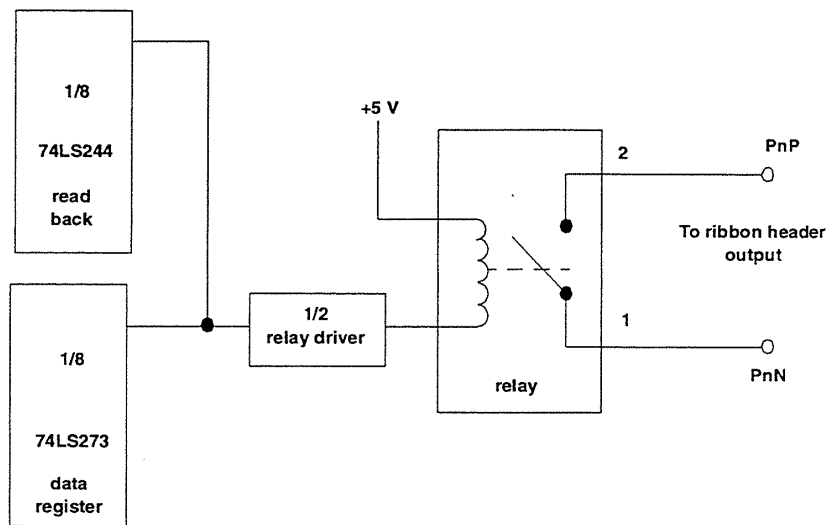


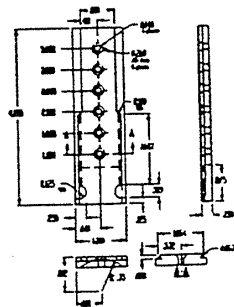
Figure 2-3. Typical Output Circuit



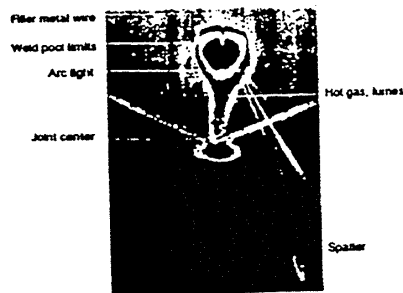
## Resolution and Accuracy

The Laser Vision camera is calibrated to work in the above mentioned optimum area. All accuracy and resolution specifications are specified for this area.

|                    | Horizontal        |                    | Vertical         |
|--------------------|-------------------|--------------------|------------------|
| Speed images/sec   | 60                | 30                 |                  |
| Resolution:        | 0.005"<br>0.125mm | 0.0025"<br>0.064mm | 0.006"<br>0.15mm |
| Accuracy position: | 0.006"<br>0.15mm  | 0.003"<br>0.076mm  | 0.008"<br>0.2mm  |
| Accuracy mismatch: |                   |                    | 0.002"<br>0.05mm |
| Accuracy gap:      | 0.012"<br>0.3mm   | 0.006"<br>0.15mm   |                  |



Camera Bracket



MVS-30 Weld pool

## Mounting

The LaserVision sensor is mounted on the torch using the camera bracket supplied. This precision machined part should be installed without any warping on a custom machined and insulated bracket mounted on the welding torch. Mounting should ensure flexibility of vertical or lateral adjustment. A 5° sensor tilt towards the torch tip is recommended. The distance to torch tip should be as short as possible, but at least 0.5" longer than the longest expected tack weld.

## Applications

The MVS-30 LaserVision sensor is a medium resolution sensor specifically designed for both tracking and inspection robotic applications. The elongated field of view helps in the initial part location, as well as the weld pool observation. It is best used for V-grooved butt joints, large lap joints and fillet joints. The maximum lap joint height is about 1" or 25mm. MVS-30 sensor is designed for MIG, subarc, plasma and fluxcore with welding currents up to 900A.

## Specifications

Speed: 60 images per second - RS170  
50 images per second - CCIR standard  
Cooling: liquid 1/4 US gallon (1l) per minute (air cooling for subarc and currents up to 50 A)  
Air: 0.11 CFM (3l per minute)  
Weight: 9oz (250g)



MVS Modular Vision Systems Inc., 3195 De Miniac, Montreal, Canada, H4S-1S9, (514)-333-0140, FAX (514)-333-8636

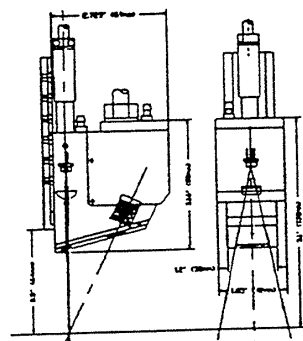




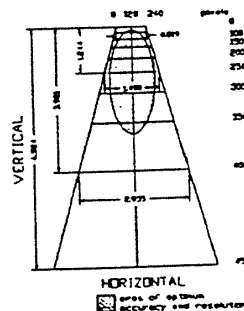
## LaserVision Sensor MVS-30 Specifications

### General

**LaserVision** is a new generation of highly *reliable* laser range (profile) sensors with *no moving parts*, specifically designed for welding and sealant dispensing applications. It is the first really *affordable* vision based sensor, providing *high processing speed* and reliable tracking with more than adequate information for statistical process control and improved parameter control. At the same time, LaserVision is *simple to use* and *rugged* enough to provide trouble free service in any welding or other hostile industrial environment. A unique patented<sup>1</sup> design allows for *over 200 hours of maintenance free operation* under extreme spatter conditions (900A fluxcore). The output from the sensor is a common TV signal, allowing the images to be recorded for the Quality Assurance on a standard VCR.



MVS-30 Outline and Optics



MVS-30 Field of View

### Principle of Operation

The LaserVision sensor uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features.

A dedicated vision processor board LPB-200 extracts the surface profile of 60 times per second - even under extreme arc light and spatter conditions. The relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, such as joint position and geometry, are extracted and measured.

### Field of View

The field of view is trapezoidal in shape (see drawing) due to the angle of observation of the laser plane. An important feature of this approach is that a straight line remains a straight line, but angles are not preserved. This geometry allows for all the tracking algorithms to be performed in the camera space. A simple set of equations, with eight coefficients obtained by the LaserVision camera calibration procedure, describes the camera space and all the range points can be easily calibrated. The shaded area is the optimum working area for the LaserVision camera where resolution is highest, focus for both the laser line and the camera is optimal and distortion of the optics is minimal.

<sup>1</sup> US patent #4,859,829, August 22, 1989. Canada, Western Europe and Japan applied for.

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### 3 LASERVISION SENSOR AND PROCESSOR

#### 3.1 Introduction

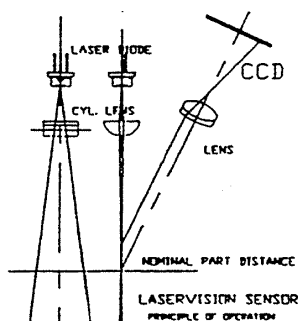


Figure 3.1.1 LaserVision Sensor  
Optics and Principle of Operation

The LaserVision sensor is a range type sensor. It uses a laser light projected in a plane approximately perpendicular to the observed joint. The cross section of the laser plane of light and the part produces a bright line. When this line is observed by a CCD camera at an angle (20° to 30°) it shows the surface features. A dedicated vision processor board LPB-200 extracts this *profile* of the surface 60 times per second even under extreme arc light and spatter conditions. A relative distance of the surface points under the sensor is then calculated (by triangulation) and features of the profile, as joint position and geometry, are calculated by an array processor SKY-320 and the AT-PC compatible computer. Each calculated joint position point is further verified, filtered and stored into the memory as a *trajectory queue*. This point is then output at appropriate moment to the positioning subsystem when the torch arrives at the position where this particular joint position is measured (see the Motion Control section of this manual).

#### 3.2 The LaserVision Sensor

**Warning: Please read LASER SAFETY INFORMATION! A serious eye injury can result if the laser safety is not respected.**

The LaserVision sensor consists of a CCD camera (a solid state TV camera) and a semiconductor laser. A pinhole, lens and filter combination serves as the objective for the CCD camera. A cylindrical lens is used to focus the laser beam into a plane of light. The beam is further restricted by the slot on the sliding protective plate. Small glass windows are used behind the slots and in front of the lens in order to further protect the lenses from spatter and metal fumes.

The entire camera is pressurized to prevent welding fumes from entering. Pressure is relieved through both the laser slot and the pinhole. In order not to disturb a gas shield around the torch the direction of the blown gas is away from the weld pool and the amount of the gas used is minimal (3.5 litres, or slightly less than one US gallon per minute). A clean pressurized air or inert gas should be used. If shop compressed air is used a reliable water, oil and dust filter should be installed in the air line. 1/8" barbed connectors are used for air and cooling water connection, suitable for 1/8" PVC tubing. The connector is rated for 150 psi of pressure when proper tubing is used.

### MVS Modular Vision Systems Inc. LaserVision Sensor & Processing

Water cooling is mandatory for open arc currents of more than 50A. Air cooling can also be used for applications of less than 50A on open arc or a subarc system with currents up to 200-300A.

The interference filters are:

- 30nm bandwidth for TIG arc up to 100A and wire feeder in front; up 50A TIG without wire feeder in front and subarc applications.
- 10nm bandwidth for higher current TIG, plasma, MIG and flux core wire.
- 5nm bandwidth for some very bright arcs, usually plasma, with use of a fibre optic laser.

In case of 10nm filter bandwidth chilled (and heated in case of low operating temperatures) water is required to maintain a precise operating temperature for the laser ( $\pm 3^{\circ}\text{C}$ ).

For more information consult the LaserVision sensor data sheets.

### 3.3 LaserVision Sensor Control and Processing

The camera video and synchronization signals are fed via the camera power supply to the LaserVision Processing Board LPB-200 (200-SYS-01). The camera power supply is factory adjusted. If required, please refer to the CCD camera and power supply information included.

The laser intensity is also controlled by the same processor board via signal IPUL (ILIN in earlier versions). A Laser Filter Board LFB-265 (265-SYS-02) provides optical isolation for the laser intensity control signal and a dedicated *floating* laser power supply connections. The laser control signal is a pulse with modulated signal with 60Hz base frequency. Maximum intensity and linearity of the control is adjusted by the potentiometer P1.

The laser power supply +5.25V and -12.0V is switched by the relay R1 by the interconnection board IB-240. The IB-240 board enables the laser only if:

- the EMERGENCY STOP is not pressed,
- there is no ALARM condition (watch-dog timer) and
- the LASER push button is engaged.

The signal received by the LPB-200 board as well as the processed profiles and tracking cursors can be observed on a profile monitor fed by the LPB-200.

For more information on the LaserVision Processing Board see the LaserVision Profile Processing Board - Technical Description

For the maintenance consult the LaserVision Camera Maintenance section.

## 4 LASERVISION PROFILE PROCESSING BOARD LPB-200

### 4.1 Introduction

MVS LaserVision Profile Board (LPB) is an image processing board specifically designed for extracting profiles of objects using a structured light and CCD camera. These profiles are generated by projecting a laser line on an object and observing it at an angle with a standard CCD video camera. Digital filtering techniques are used in order to ensure reliable operation in a high noise environment (i.e. arc welding) and suppress reflection artifacts.

LPB plugs into a single slot of an IBM-AT compatible computer.

### 4.2 LPB Main Features

The LPB can be used either alone as the only vision module in the system or with additional modules for increased performance, such as the DSP board with the Texas Instrument DSP processor TMS32010. A separate output port is provided for the transfer of profile data to the DSP board.

The principal features of the LPB module:

- Camera input, digitized at 8 bit per pixel.
- High resolution of 512 pixels per line standard.
- Highly stable digital phase locked loop synchronization of the internal pixel clock to the horizontal sync signal. A non cumulative jitter is less than  $\pm 12\%$  of the pixel clock period, allowing for sub-pixel measurement accuracy. A reliable operation is achieved even with the standard VCR.
- Two groups of 2Kx8 (8Kx8 optional) bit input Look-up Tables, one group for processing and other for histogram.
- Monitor output with 8Kx8 (32Kx8 optional) bit output Look-up Tables.
- Histogram circuit for 256 possible levels operating either on entire frame or area of interest window.
- Real time digital filter for the accurate feature extraction (profile)
- Profile extractor stores x, y coordinates and intensities of the most probable line points into 2Kx16 (8Kx16 optional) profile memory capable to contain 4 (16) profile vectors of 240 coordinates. This memory is accessible either to the AT host or a separate DSP processor board via a DSP output port.
- Eight selectable Area of Interest windows, easily movable around the picture area by specifying only the X-Y offset coordinates. Both histogram and profile extractor can be set to work only within this area of interest window.

- Flexible RAM based video clock and cursor generation allows for easy synchronization with wide range of standard and nonstandard video inputs.
- Capability to display "raw" profile or other intermediate results by simply loading pixel coordinate for each line into FIFO circuit.
- Laser intensity control output at 8 bit resolution.

#### 4.3 Functional Overview

Main functions of the LaserVision Profile Board are shown on the Block Diagram (LPB.DWG).

The LaserVision camera is connected directly to the LPB via the provided cable. External synchronization is normally used, but there is a provision to use internal sync extraction from the video signal (VCR use) with some sacrifice in vertical positioning accuracy. Generation of internal synchronization signals is RAM based and allows for nonstandard video signals.

Initialization program supplied with the LPB loads necessary values for the RS-170 standard (North American B&W video) or CCIR standard (European) depending on type of camera. Same memory also serves for generation of two independent cursors.

The video signal coming from the camera is first conditioned then digitized to 8 bit accuracy. Two sets of look-up tables are provided, one for the digital filter and other for the histogram circuit. This allows entirely independent operation of the histogram circuit.

The digital filter is optimized for both noise suppression and laser line signal extraction. The laser line signals are enhanced and all other noise signals as ambient light are attenuated.

The digital filter circuit is followed by the profile extraction circuit. This circuit selects the peak of the laser line signal for each active video line and stores the result into Profile Memory during the horizontal blanking interval.

Results stored in the Profile Memory are accessible for further processing either by the host computer or via the DSP Output Port by the DSP board.

In order to further improve the noise immunity of the processing the LPB features the Area of Interest Window. Up to 8 different windows can be stored into window memory. Windows are selected through the control registers and they can easily be moved around the active video frame via X-Y offset registers. Both Histogram and Peak detector circuits can be set to operate only within the window and to ignore areas outside the window.

Typically the window shape is selected to closely match the expected joint profile. Once the joint profile is recognized and tracked, the window is set to closely follow the joint profile. Thus any noise outside the window of interest is automatically rejected. The described windowing technique also improves rejection of reflection artifacts.

The calculated profile or results of other intermediate calculations can be displayed on the monitor via the FIFO (first in first out) circuit. The FIFO has depth of 512 9 bit words, and it can be accessed via a single port. Total of 512 accesses fills the FIFO memory. When activated, the content of the FIFO memory is read synchronously with every active video line starting from the "zero" location. A single dot is output to the screen for every of 480 active lines at the pixel position equal to the address value stored into the corresponding FIFO location. The same output is automatically replayed every video frame without further program intervention.

#### MVS Modular Vision Systems Inc. LaserVision Sensor & Processing

The Output Look-Up Table circuit assigns gray levels to the digital filter results and the filtering operation can be observed in real time on the monitor. Windows, profile (FIFO) and cursors are displayed as bright overlay.

#### 4.4 Specifications

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Camera Input:   | Video: 1Vpp<br><br>Sync: TTL compatible, Standard RS170 or CCIR, other standards can be programmed.                                                                                                                                                                                                                                                                                                                                                                                   |
| Monitor Output: | RS170 or CCIR Composite sync.                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Digitization:   | Rate: 9.8304 Mhz standard<br><br>Resolution: 8 bits.<br><br>Jitter: less than +/- 12% of pixel width, Non cumulative.                                                                                                                                                                                                                                                                                                                                                                 |
| Processor:      | IBM-AT compatible, up to 8 Mhz, bus speed, requires 64K memory mapped space.                                                                                                                                                                                                                                                                                                                                                                                                          |
| Output Port:    | 16 bit data, TTL compatible handshake control, up to 10 Mhz transfer rate, SKY320 compatible.                                                                                                                                                                                                                                                                                                                                                                                         |
| Measurements:   | Width resolution: 240 points at 60 images per second, 480 points at 30 images per second, RS170 standard, or 256 points at 50 images per second, 512 points at 25 images per second, CCIR standard.<br><br>Height resolution: 512 points.<br><br>Nonlinear field of view due to triangulation technique used, however straight lines in actual space remain straight lines in transformed (camera) space. Calibration can be applied on final results only (i.e. after segmentation). |

## 2.3 S-Series Motor Specifications (TENV) [5]

| Model                                   | S-2003  | S-2005   | S-3007  | S-3016  | S-4030  | S-4050  | S-4075  | S-6100 | S-6200 | S-6300 | S-8350 | S-8500 |
|-----------------------------------------|---------|----------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|
| Stall Torque (lb-in)                    | 2.7     | 5.0      | 7.0     | 20      | 30      | 60      | 90      | 100    | 200    | 325    | 350    | 450    |
| (Nm)                                    | 0.30    | 0.56     | 0.79    | 2.26    | 3.39    | 6.78    | 10.2    | 11.3   | 22.6   | 36.7   | 39.5   | 50.8   |
| Speed (rpm) <sup>(1)</sup>              | 6000    | 6000     | 5000    | 5000    | 4000    | 4000    | 3000    | 3000   | 3000   | 3000   | 2000   | 2000   |
| K <sub>t</sub> (lb-in/A) <sup>(2)</sup> | 1.17    | 1.17     | 2.5     | 2.5     | 4.4     | 4.4     | 6.7     | 6.0    | 5.8    | 6.2    | 7.6    | 8.2    |
| (Nm/A)                                  | 0.13    | 0.13     | 0.28    | 0.28    | 0.50    | 0.50    | 0.76    | 0.68   | 0.66   | 0.70   | 0.86   | 0.92   |
| K <sub>e</sub> (V/krpm) <sup>(3)</sup>  | 16      | 16       | 34      | 34      | 60      | 60      | 90      | 82     | 80     | 85     | 104    | 112    |
| R (ohms) <sup>(4)</sup>                 | 7.3     | 2.6      | 6.6     | 1.3     | 2.0     | 0.8     | 0.9     | 0.49   | 0.18   | 0.12   | 0.13   | 0.10   |
| L (mH) <sup>(4)</sup>                   | 9.7     | 4.1      | 12.0    | 3.4     | 9.0     | 3.3     | 5.4     | 4.4    | 2.2    | 1.2    | 2.5    | 2.4    |
| J (lb-in-s <sup>2</sup> )               | 0.00007 | 0.00013  | 0.00027 | 0.00072 | 0.0022  | 0.0041  | 0.006   | 0.012  | 0.021  | 0.030  | 0.056  | 0.083  |
| (kg-m <sup>2</sup> )                    | .000008 | 0.000015 | 0.00003 | 0.00008 | 0.00025 | 0.00046 | 0.00068 | 0.0013 | 0.0024 | 0.0034 | 0.0063 | 0.0094 |
| BRU-500                                 | —       | —        | DM-25   | DM-25   | DM-25   | DM-50   | DM-50   | DM-50  | DM-100 | DM-150 | DM-100 | DM-150 |
| BRU-200                                 | DM-10   | DM-10    | DM-10   | DM-20   | DM-20   | DM-30   | DM-30   | —      | —      | —      | —      | —      |

- [1] maximum continuous operating speed
- [2] peak amps of per phase sine wave
- [3] peak volts of line to line sine wave
- [4] phase to phase
- [5] totally enclosed nonventilated

## SECTION II - SPECIFICATIONS

### 2.1 Drive Module Specifications

| <u>BRU-500 Model</u>       | <u>DM-25</u>                                | <u>DM-50</u> | <u>DM-100</u> | <u>DM-150</u> | <u>DM-150X</u> |
|----------------------------|---------------------------------------------|--------------|---------------|---------------|----------------|
| Continuous Amps[1]         | 20                                          | 40           | 50            | 65            | 85             |
| Peak Amps[1]               | 25                                          | 50           | 100           | 150           | 150            |
| Bus Voltage                | 125-375 VDC<br>(325 VDC with 230 VAC input) |              |               |               |                |
| Command Signal Input Range | $\pm 10$ VDC (13.3k Ohms impedance)         |              |               |               |                |
| Ambient Temp.              | 32° -122° F (0° -50° C)                     |              |               |               |                |
| Weight                     | 24.2 lbs (11.0 kg)                          |              |               |               |                |

| <u>BRU-200 Model</u>       | <u>DM-10</u>                                | <u>DM-20</u> | <u>DM-30</u> |
|----------------------------|---------------------------------------------|--------------|--------------|
| Continuous Amps [1]        | 5                                           | 10           | 15           |
| Peak Amps [1]              | 10                                          | 20           | 30           |
| Input Volts                | 88-265 VAC RMS (Single Phase)               |              |              |
| Internal DC Bus Voltage    | 125-375 VDC<br>(325 VDC with 230 VAC Input) |              |              |
| Command Signal Input Range | $\pm 10$ VDC (13.3k Ohms impedance)         |              |              |
| Continuous Shunt Power [2] | 50 W                                        |              |              |
| Peak Shunt Power [2]       | 4.5 kW                                      |              |              |
| Ambient Temp.              | 32° -122° F (0° -50° C)                     |              |              |
| Weight                     | 11 lbs (5 kg)                               |              |              |

[1] peak value of sine wave per phase

[2] DM-30 has provision for optional external shunt resistor that provides 200 W continuous and 6000 W peak shunt power. See drawing 9101-1104 in Section X for additional details.



## Linear Positioner Series Introduction

### General

Jasta-Dynact's Linear Positioner or "Rodless Cylinder" series are high quality units designed for applications where long stroke lengths, high velocities, and precise resolution and repeatability are necessary.

### Stroke length

See the table below for all stroke lengths available per series. Final stroke length depends on screw velocity desired.

### Gearing

Jasta-Dynact's standard gear ratios for the linear positioners are also listed in the table below. The letter "D" designates "direct drive" and The letter "T" represents a "timing" belt drive. All numbers following each specified letter represent the ratio available. Please refer to page 6 for more information.

### Drive screws and Drive Chains

"Screw" drive linear positioners use 3 types of drive screws: Vee (V), Acme (A), and Ball (B). The number after the letter designates the screw pitch, as listed in the table below. Please refer to pages 4-5 for more information on drive screws. "High-velocity" or "Cable chain" drive linear positioners use drive chains for maximum velocity. (see page 47).

### Motors

Jasta-Dynact offers a wide variety of motors. Any number preceding the letter "D" relates to the voltage of the motor, and the number preceding the letter "S" relates to the frame size of the step motor. The number following the letters "D", "BU", and "S" designates the size of the motor relative to the sizes within its category. Please refer to pages 13-16 for more information.

| Model     | *Stroke Length<br>(*Approximate) | Gearing            | Drive Screws                    | Motors                    |
|-----------|----------------------------------|--------------------|---------------------------------|---------------------------|
| LP 050    | 0-20 Inches                      | D1                 | V40, V20, A4, A2, A1            | 17S1, 24D1 & BU50         |
| LP 100    | 0-72 Inches                      | D1, T1, T2 & T2.67 | V20, B8, B5.5, A10, A5, A2 & A1 | 24D4, 90D2, BU100, & 23S4 |
| LP 150    | 0-72 Inches                      | D1, T1 & T2        | V20, A10, A5, A2, B5 & B2       | 24D5, 90D3, BU200, & 34S1 |
| LP 100 HV | 0-20 Feet                        | D1 & T2            | N/A                             | 24D4, 90D2, BU100, & 23S4 |
| LP 150 HV | 0-20 Feet                        | D1 & T2            | N/A                             | 24D5, 90D3, BU200, & 34S1 |

### Options

Various options adding to the operation of the linear positioners are (BR) Electromechanical Fail-Safe Brake, (MSR) Magnetic Switch Relay, (MS) Magnetic Reed Switch, (ES) Environmentally Sealed, (ZN) Anti-Backlash Nut, (LZ) Low-Backlash Ball Nut, (EN) Optical Encoder, (CN) Brake or Encoder Canister, (CND) Brake and Encoder Canister, and (GRS) Guide-Rail Supports. Please refer to pages 53-55 for more information.

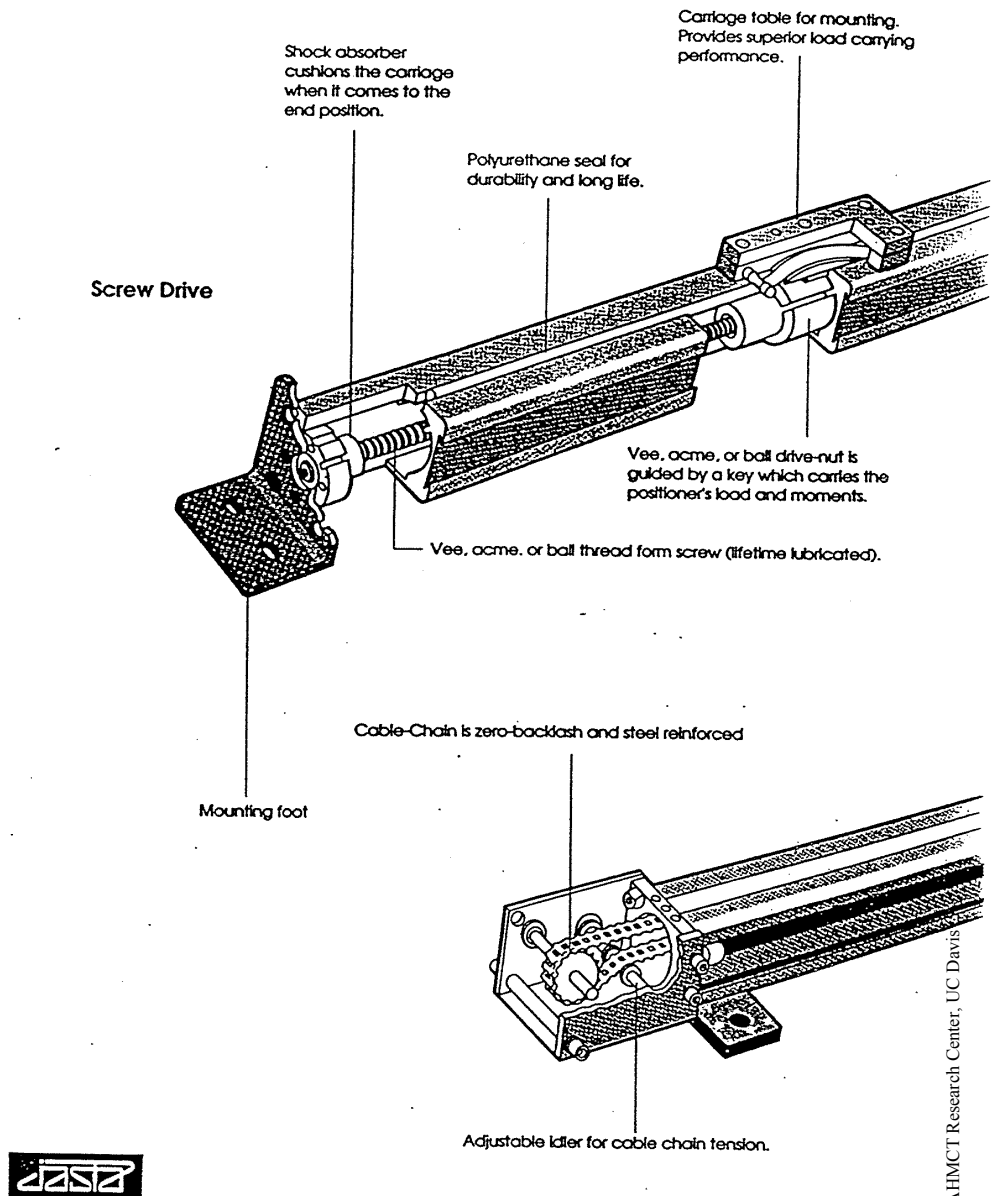
### Mounting

"Screw" drive linear positioners can also be manufactured where the motor is mounted parallel to the drive screw, as in the case of an actuator for instance. This alternative method of operation is available for the linear positioner "screw" drive series only. (refer to page 51). "High-velocity" linear positioners are mounted where the motor is perpendicular to the cylinder body.

**Clamp-On Foot Mount (CFM) option:** The "Clamp-on Foot Mount" (CFM) may be substituted for the standard linear positioner foot mounts. (See pages 38, 41 and 42).

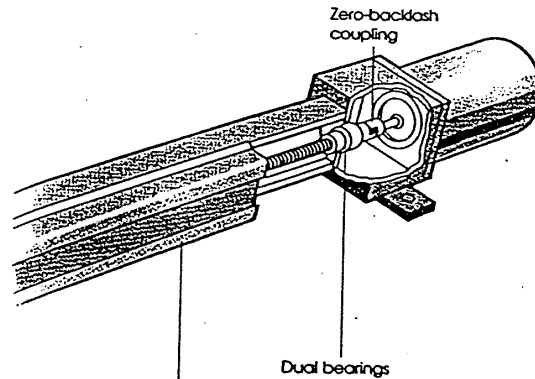
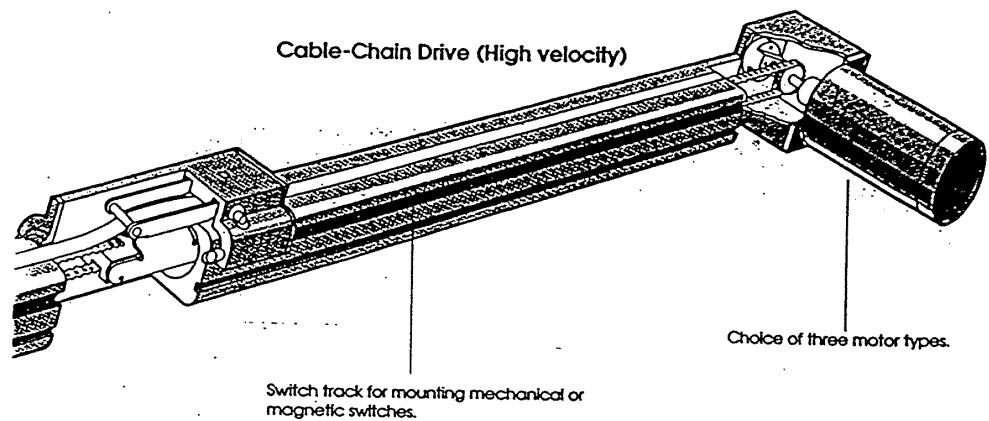


## Linear Positioner Features



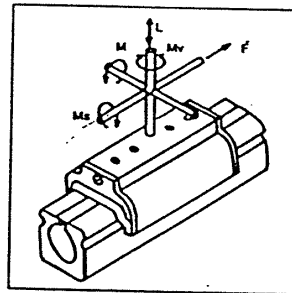
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## Linear Positioner Features



# Linear Positioner Specifications

## Screw Drive



Load, Thrust, and Bending Moments Diagram

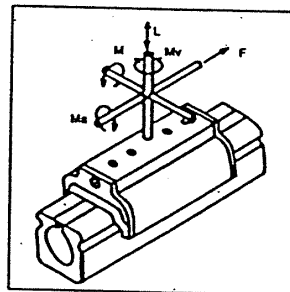
Load, Thrust, and Bending Moments Specifications

| Model Number | Maximum Bending Moment |                    |                   | Maximum Load/lbs. (6) | Maximum Thrust/lbs. (7) |
|--------------|------------------------|--------------------|-------------------|-----------------------|-------------------------|
|              | Pitch (4) In./lbs.     | Roll (5a) In./lbs. | Yaw (5b) In./lbs. |                       |                         |
| LP 050       | 10                     | 5.5                | Δ                 | 10                    | 10                      |
| LP 100       | 100                    | 55                 | 30                | 60                    | 200                     |
| LP 150       | 500                    | 175                | 200               | 180                   | 400                     |

Weight Specification Table

| Model Number | Base Weight w/Motor | Weight per Inch of Stroke |
|--------------|---------------------|---------------------------|
| LP 050       | 1.3 lbs.            | .04 lbs.                  |
| LP 100       | 6.2 lbs.            | .23 lbs.                  |
| LP 150       | 19 lbs.             | .50 lbs.                  |

## Belt Drive (High-Velocity)



Load, Thrust, and Bending Moments Diagram

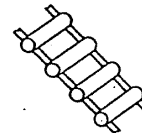
Load, Thrust, and Bending Moments Specifications

| Model Number | Maximum Bending Moment |                    |                   | Maximum Load/lbs. (6) | Maximum Thrust/lbs. (7) |
|--------------|------------------------|--------------------|-------------------|-----------------------|-------------------------|
|              | Pitch (4) In./lbs.     | Roll (5a) In./lbs. | Yaw (5b) In./lbs. |                       |                         |
| LP 100 HV    | 100                    | 55                 | 30                | 60                    | 50                      |
| LP 150 HV    | 500                    | 175                | 200               | 180                   | 60                      |

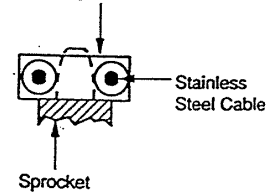
Cable Chain Specification Table

| Model Number | Drive Pulley Circumference | Maximum Thrust |
|--------------|----------------------------|----------------|
| LP 100 HV    | 2.50 inches                | 100 lbs.       |
| LP 150 HV    | 4.00 inches                | 100 lbs.       |

Cable Chain



Polyurethane



Sprocket

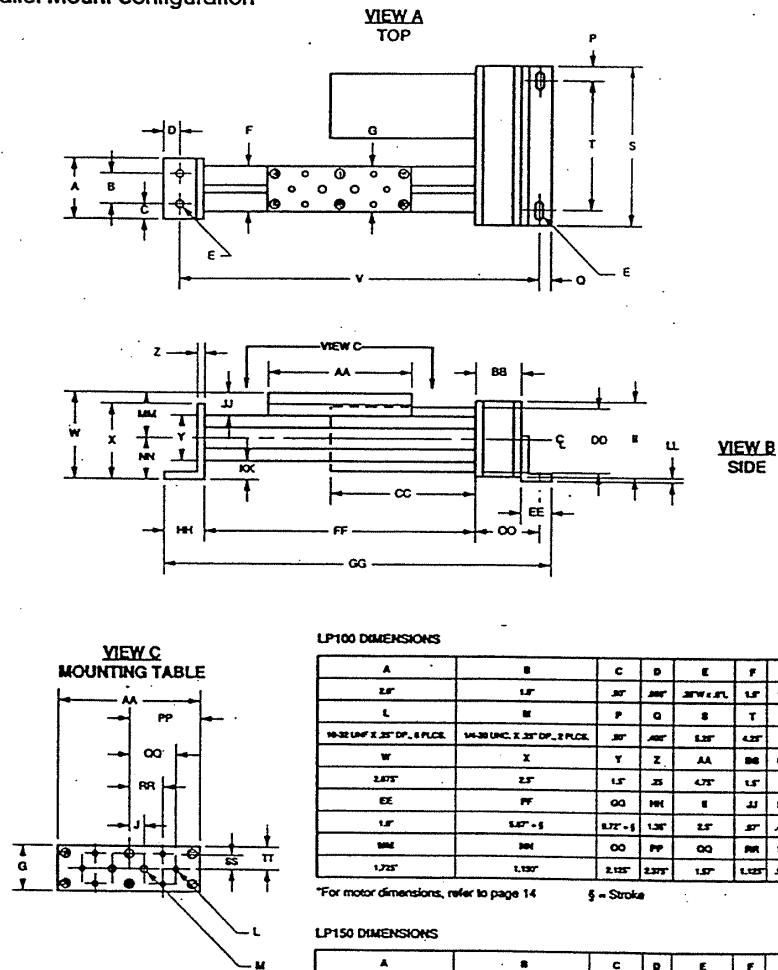
Weight Specification Table

| Model Number | Base Weight w/Motor | Weight per Inch of Stroke |
|--------------|---------------------|---------------------------|
| LP 100 HV    | 6 lbs.              | .16 lbs.                  |
| LP 150 HV    | 18 lbs.             | .34 lbs.                  |



# Linear Positioner Dimensions (Screw Drive)

Parallel Mount configuration



LP100 DIMENSIONS

| A                             | B                             | C          | D      | E           | F      | G          | J     |
|-------------------------------|-------------------------------|------------|--------|-------------|--------|------------|-------|
| 1.8"                          | 1.8"                          | .80"       | .80"   | .80" ± .01" | 1.5"   | 1.5"       | .80"  |
| L                             | M                             | P          | Q      | R           | T      | V          |       |
| 14-32 UNF X .25" DP., 6 PLCS. | 14-32 UNF X .25" DP., 2 PLCS. | .80"       | .80"   | 5.30"       | 4.30"  | 6.80" ± .5 |       |
| W                             | X                             | Y          | Z      | AA          | BB     | CC         | DD    |
| 3.675"                        | 2.5"                          | 1.5"       | .25    | 4.75"       | 1.5"   | -          | -     |
| EE                            | FF                            | GG         | HH     | I           | JJ     | KK         | LL    |
| 1.8"                          | 5.80" ± .5                    | 6.75" ± .5 | 1.30"  | 3.5"        | .80"   | .125"      |       |
| MM                            | NN                            | OO         | PP     | QQ          | RR     | SS         | TT    |
| 1.725"                        | 1.100"                        | 2.125"     | 2.375" | 1.50"       | 1.125" | .800"      | .750" |

\*For motor dimensions, refer to page 14 § = Stroke

LP150 DIMENSIONS

| A                                | B                                | C            | D      | E             | F     | G            | J     |
|----------------------------------|----------------------------------|--------------|--------|---------------|-------|--------------|-------|
| 2.4"                             | 1.5"                             | .85"         | 1.25"  | .80" W ± .01" | 2.25" | 2.25"        | 1.00" |
| L                                | M                                | P            | Q      | R             | T     | V            |       |
| 5/16-18 UNC X .375" DP., 2 PLCS. | 5/16-18 UNC X .375" DP., 2 PLCS. | 1.0"         | .825"  | 6.30"         | 4.30" | 12.825" ± .5 |       |
| W                                | X                                | Y            | Z      | AA            | BB    | CC           | DD    |
| 4.5"                             | 3.80"                            | 2.30"        | .25    | 5.30"         | 2.00" | -            | -     |
| EE                               | FF                               | GG           | HH     | I             | JJ    | KK           | LL    |
| 1.5"                             | 6.80" ± .5                       | 14.575" ± .5 | 2.25"  | 3.5"          | 1.10" | .8125"       | .125" |
| MM                               | NN                               | OO           | PP     | QQ            | RR    | SS           | TT    |
| 2.25"                            | 1.80"                            | 2.875"       | 2.375" | 2.125"        | 1.50" | .75"         | 1.10" |



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## Drive Screws and Nuts

### General Description

The screws used in Jasta actuators and positioners are "rolled" screws with a lead accuracy of  $\pm 0.003$  to  $\pm 0.005$  inch per foot of screw. "Ground" screws are available at a considerably higher price. The ground screw lead error is  $\pm 0.0005$  inch per foot of length, non-accumulative.

### Lubrication

All Jasta actuators and linear positioners are factory lubricated with the proper screw lubricants for the life of the particular unit. For special applications; i.e., extremely high or low temperature or for vacuum operation, Jasta will lubricate accordingly.

### Materials

Jasta Vee and Acme screws are cold-rolled 1018 steel or stainless steel if required. Most Jasta Ball screws are 1018 steel hardened to RC65.

### Designation

The screw designation is used throughout this catalog. To interpret the designation, the letter (V, A, or B) designates the screw type, and the number following the letter designates the screw pitch, as described in the table below.

### Pitch

This designates the number of threads per inch of screw (i.e., V20 is a Vee thread form with 20 threads per linear inch).

### Lead

The screw lead is the linear distance the screw drive nut will move for each revolution of the screw (i.e., V20 = 1.00 inch/20 threads = 0.05 inch/revolution).

### Efficiency (e)

The screw efficiency is determined by measuring the torque required to rotate the screw in order for the drive nut to lift a known load.

$$e = \text{Load (Lbs.)} \times \text{screw lead} \times 16 \text{ oz./lb.} \\ + 2\pi \times \text{Torque (oz./in.)}$$

### Specifications

Jasta linear actuators and positioners utilize the drive screws listed in the Table below. Each actuator is given a catalog size reference. For example:

Size 1 = Mite, Mini-Pulse, PP I, and Mini-Jac  
Size 2 = Act I, Act II, Jasta-Jac, PPII and PPIII  
Size 3 = Brute

### Type

Jasta actuators and positioners are available with three types of screws: Vee thread, Acme thread, and Ball thread. Vee thread screws offer very fine leads and are quite useful for applications not requiring high velocities, high loads or high duty cycles. Acme screws are very useful in applications where noise is a consideration because they are generally quieter running. The acme also offers a wide variety of screw diameters and leads, can be self-locking and is less expensive when compared to ball screws. Ball screws have many advantages over acme and vee thread screws such as: higher efficiencies, higher speeds, higher loads, higher duty cycles, less friction and longer life.

\*Efficiencies in the table below are based on Delrin AF drive nuts on the Vee and Acme screws, and ball nuts on the ball screws.

For Bronze nuts reduce the efficiency of Delrin AF nuts in the Table by 5%.

### Drive Screw Data

| Designation               | V40   | V20   | A10   | A5    | A2    | A1    | B8.5  | B8    | B5    | B2   |
|---------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| Thread Form               | Vee   | Vee   | Acme  | Acme  | Acme  | Acme  | Ball  | Ball  | Ball  | Ball |
| Pitch                     | 40    | 20    | 10    | 5     | 2     | 1     | 8.5   | 8     | 5     | 2    |
| Lead                      | .025" | .05"  | .10"  | .2"   | .5"   | 1.00" | .118" | .125" | .20"  | .50" |
| Efficiency                | .18   | .25   | .30   | .40   | .60   | .65   | .90   | .90   | .90   | .90  |
| Backdrive*                | No    | No    | No    | No    | Yes   | Yes   | Yes   | Yes   | Yes   | Yes  |
| Max. Duty                 | 40%   | 50%   | 60%   | 60%   | 70%   | 80%   | 100%  | 100%  | 100%  | 100% |
| Actuator Size 1 Diameters | .375" | .375" | .375" | .375" | .375" | .375" | .397" | .375" | N/A   | N/A  |
| Actuator Size 2 Diameters | N/A   | .50"  | .50"  | .50"  | .50"  | .50"  | N/A   | N/A   | .625" | .50" |
| Actuator Size 3 Diameters | N/A   | .75"  | .75"  | N/A   | N/A   | N/A   | N/A   | N/A   | .75"  | .75" |

\*The higher the lead of the screw the less effort required to backdrive either the screw or the nut. As a rule, the lead of the screw should be more than 1/3 the diameter of the screw to satisfactorily backdrive.

N/A = Non-Applicable



## Drive Screws and Nuts

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### Screw Linear Velocity

All screw types are limited as to the speed to which a screw may be rotated. At a particular speed for a particular screw, the "critical velocity" of the screw will be reached, causing the screw to whip and vibrate, thereby becoming unstable and unusable. This critical velocity is a result of screw rotational speed, screw diameter, and screw length (refer to page 11).

### Screw Life

The operating life of Jasta linear actuators and positioners is dependent on numerous factors: stroke velocity, thrust, load, moment, environment, screw type, motor type and duty. Upon selecting an actuator or positioner for a continuous duty operation, choose a ball screw and nut along with a motor rated for continuous duty (100%). Acme screws (with leads below .5") and nuts are relatively high-friction with efficiencies of less than 60%, and generate heat at high linear velocities and high duty cycles. Ball screw/nut combinations have efficiencies of 90% and are designed for higher loads and speeds. Once an actuator is properly selected, the life can range to a high-end of 50 million cycles for a ball screw model under normal conditions.

### Drive Nuts



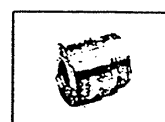
Ball Nut



Delrin AF Nut



Anti-Backlash  
Acme Nut



Bronze Nut

### Ball Nut

Jasta "Ball" nuts utilize high quality steel ball nuts with recirculating steel balls for long life and heavy loads. Normal backlash is approximately .002" to .004".

### Delrin AF Nut

The "Delrin AF" drive nut is a combination delrin and teflon plastic drive nut, utilized in all Jasta acme and vee threads for actuator loads under 500 lbs. Some advantages of this nut are its quiet running and low friction operation.

### Anti-Backlash Acme Nut

The Delrin AF "ZN" nut (Anti-backlash Acme Nut) is available with a zero backlash design. This is accomplished by preloading the nut by spring compression.

### Bronze Nut

A Bronze drive nut is used on acme screws in applications where thrust requirements exceed 500 lbs. Its main advantage is its heavy load capability.



## Gearing

Jasta actuators are driven by three types of gear reduction:

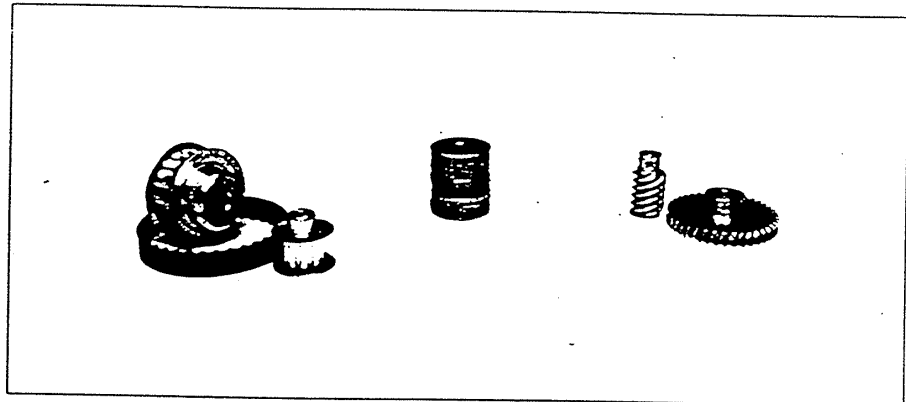
1. Synchronous (timing) belts and pulleys
2. Worm gear drives
3. Inline drive (no gear reduction)

### Designation

All gearing has a specific designation thru-out this catalog. "T" represents a "timing belt drive". "W" represents a "worm gear" or "right angle" drive, and "D" represents a "direct drive."

### Ratios

Ratios are described by the number following the letter representing the type of gearing.  
For instance: T2 = Timing belt (2:1 ratio) D1 = Direct drive (1:1 ratio) W10 = Worm gear (10:1 ratio)



#### Synchronous Belts and Pulleys:

The majority of Jasta actuators use a no-slip, very low backlash, synchronous belt drive known as timing belts.

Timing belts and pulleys have the following advantages over spur and worm gears:

- A) Long life
- B) Low backlash
- C) No lubrication required
- D) Quiet running
- E) Unaffected by minor mis-alignments
- F) High efficiency - 90% +

#### Worm Gear (Right angle) Drives:

Jasta utilizes worm gear drives in the Jasta Jac and Mini Jac series of actuators. The advantage of the worm gear is a high ratio in a small space and high loading capability; however, the gear efficiency is low ~50%.

Jasta worm gear ratios available:

- 10:1
- 20:1
- 40:1

\*The 40:1 ratio with a ball screw will not backdrive under load.

#### Inline Drive (Direct Coupled):

Jasta Pulse Power series use a direct drive with no gear reduction. The motor shaft is coupled directly to the drive screw with a high quality zero-backlash coupling.

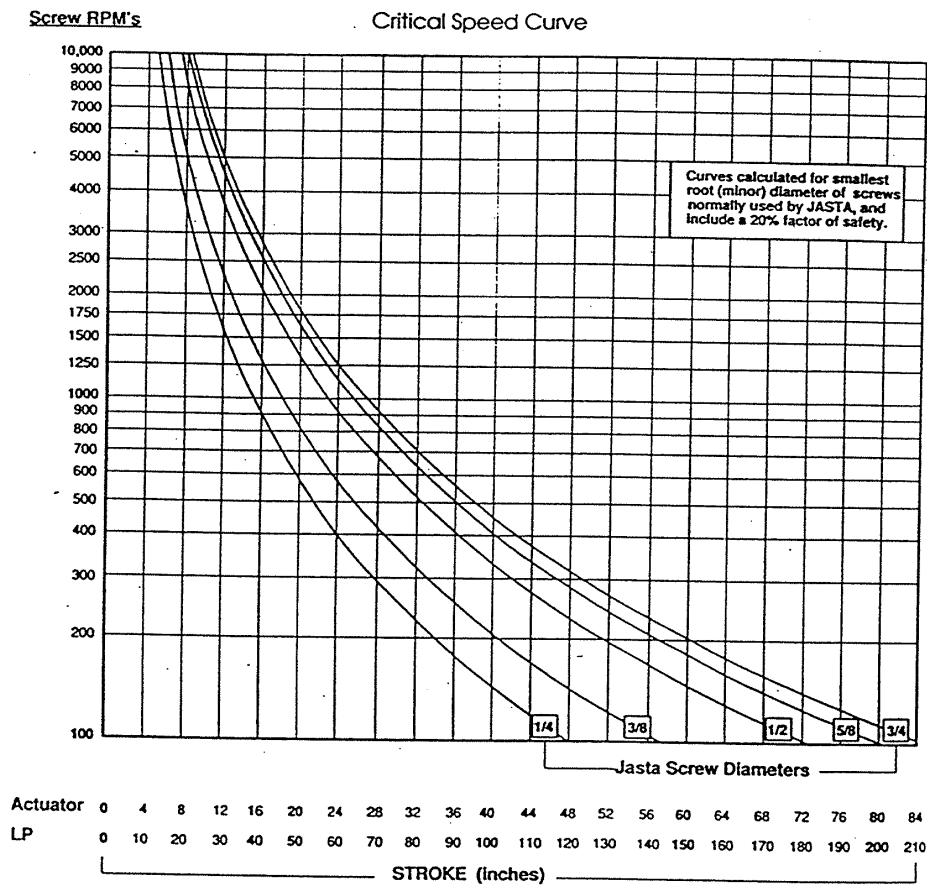
The advantages with direct inline coupling are:

- A) Zero-backlash
- B) Long life
- C) No gear noise
- D) Highest efficiency





Selecting an Actuator



## Selecting an Actuator

**Step 9:** Using the motor curve selected from STEP 8, verify that the required torque and speed fall into the correct duty cycle area, as indicated within the curve area by being either shaded or nonshaded; i.e., 100%, 60%, 30%, or 10%.

**Step 10:** Use the table in FIGURE 7 to determine the resolution and repeatability of the actuator selected.

| Screw   | Screw Lead (in.) | Repeatability $\pm$ in. |              |            | Resolution (in.)<br>200 steps per screw rotation |
|---------|------------------|-------------------------|--------------|------------|--------------------------------------------------|
|         |                  | *24VDC Motor            | *90VDC Motor | Step Motor |                                                  |
| V40     | .025             | .003                    | .005         | .0005      | $125 \times 10^{-6}$                             |
| V20     | .05              | .003                    | .005         | .0005      | $25 \times 10^{-5}$                              |
| A10     | .10              | .003                    | .006         | .0005      | $5 \times 10^{-4}$                               |
| B8-B8.5 | .125/.118        | .003                    | .006         | .0005      | $6.25 \times 10^{-4}$                            |
| A5-B5   | .20              | .004                    | .006         | .0005      | $1 \times 10^{-3}$                               |
| A2-B2   | .50              | .008                    | .010         | .0005      | $2.5 \times 10^{-3}$                             |
| A1-B1   | 1.00             | .010                    | .015         | .0005      | $5 \times 10^{-3}$                               |

\*Repeatability figures are based on positioning by limit switches.

Figure 7

**Step 11:** Consider the environmental requirements that may be involved in the particular application; i.e., dust, water, wash downs, extremely high or low temperature, corrosives, etc. Jasta actuators can handle many extreme conditions. Check with the factory for special requirements.

**Step 12:**

Ensure the load is acting down the centerline of the translating tube as shown in FIGURE 8. Only the linear positioners can take bending moments. External linear guides should be incorporated to eliminate bending moments on all other Jasta actuators.

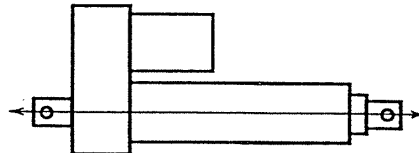


Figure 8

**Step 13:** Mounting requirements can be determined by referring to the "Mounting Components" section on pages 37-43.

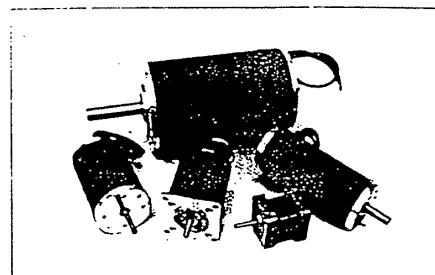
**Step 14:** Refer to pages 54-56 for options that may be added to enhance actuator performance.



## Motor Data

The motors utilized by Jasta on linear actuators and positioners fall into one of four categories:

1. Permanent magnet, brush type direct current motors, which are available in 12, 24, and 90 VDC.
2. Permanent magnet, brush type servo motors: which are available in 24 and 90 VDC.
3. Permanent magnet, direct current two and four phase step motors, with 200 or 400 steps per revolution.
4. Brushless servo motors with complete control systems, which are available in 115 VAC or 230 VAC input to amplifier.



\*Jasta will also install the motor of your choice if it meets Jasta's installation requirements.

| Motor Type                | Advantages                                                                                                                                                                                                                                                                                            | Disadvantages                                                                                                                         |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Permanent Magnet DC Brush | <ul style="list-style-type: none"> <li>•Economical</li> <li>•Fast acceleration</li> <li>•High speed</li> <li>•High Torque in a small frame</li> <li>•Maximum Torque at stall</li> <li>•No starting capacitors required</li> <li>•Speed controllable</li> </ul>                                        | <ul style="list-style-type: none"> <li>•Brush wear</li> <li>•Electromagnetic Interference</li> </ul>                                  |
| Permanent Magnet DC Servo | <ul style="list-style-type: none"> <li>•All of the above</li> <li>•Better precision</li> <li>•Better brushes</li> </ul>                                                                                                                                                                               | <ul style="list-style-type: none"> <li>•Same as above</li> </ul>                                                                      |
| Step Motor                | <ul style="list-style-type: none"> <li>•Long life</li> <li>•No brushes</li> <li>•Moderate cost</li> <li>•High Torque</li> <li>•Continuous duty</li> <li>•Precision</li> </ul>                                                                                                                         | <ul style="list-style-type: none"> <li>•Low to moderate speed</li> <li>•Electromagnetic Interference</li> <li>•Hot running</li> </ul> |
| Brushless Servo           | <ul style="list-style-type: none"> <li>•No brushes</li> <li>•High Speed</li> <li>•High Torque in a small frame</li> <li>•Fast acceleration/deceleration</li> <li>•Incremental or Absolute encoder</li> <li>•Speed and/or positioning control</li> <li>•Continuous duty</li> <li>•Long life</li> </ul> | <ul style="list-style-type: none"> <li>•Most expensive</li> </ul>                                                                     |

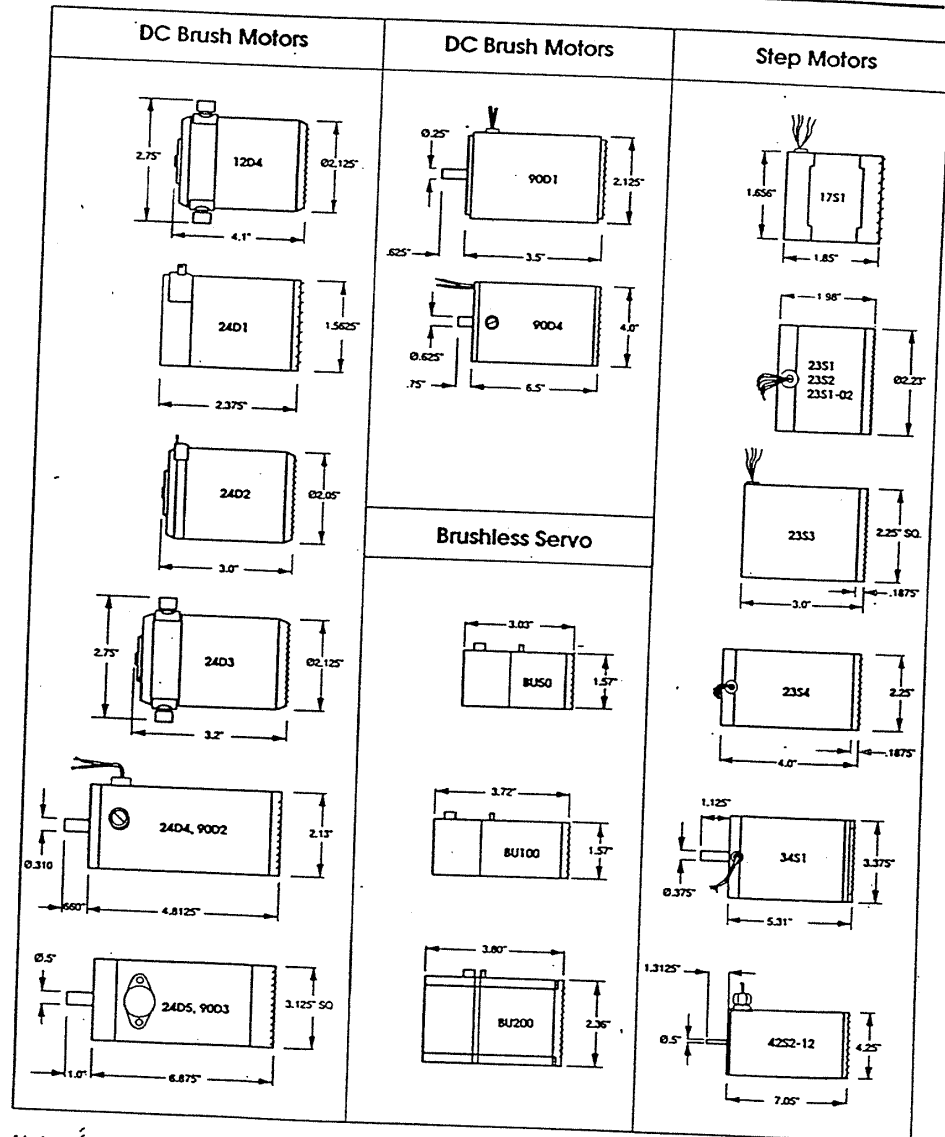


## Motor Specifications

| DC Motors                                                                                                                                                                                                   |              |                       |                       |                     |                      |                                                                                                                                    |                  |                 |                     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------------------|-----------------------|---------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------|---------------------|
| Motor Number                                                                                                                                                                                                | Voltage (DC) | Stall Torque (in.-oz) | Cont. Torque (in.-oz) | Stall Current (Amp) | KT (in.-oz /Amp)     | KE (Volts/ Krpm)                                                                                                                   | Resistance (Ohm) | Inductance (Mh) | No Load Speed (rpm) |
| 12D4                                                                                                                                                                                                        | 12           | 204                   | 32                    | 43.7                | 4.33                 | 3.21                                                                                                                               | .27              | .4              | 3700                |
| 24D1                                                                                                                                                                                                        | 24           | 24                    | 4                     | 3.3                 | 4.0                  | 3.2                                                                                                                                | 4.1              | 3.3             | 7300                |
| 24D2                                                                                                                                                                                                        | 24           | 42                    | 7                     | 8                   | 5.3                  | 3.7                                                                                                                                | 3.1              | 5.1             | 5100                |
| 24D3                                                                                                                                                                                                        | 24           | 107                   | 16                    | 13.9                | 7.8                  | 5.77                                                                                                                               | 1.73             | 2.54            | 4087                |
| 24D4                                                                                                                                                                                                        | 24           | 275                   | 40                    | 33.3                | 8.4                  | 6.2                                                                                                                                | .72              | 4.0             | 4300                |
| 24D5                                                                                                                                                                                                        | 24           | 1000                  | 90                    | 136                 | 7.35                 | 5.56                                                                                                                               | .5               | 5.0             | 3500                |
| 90D1                                                                                                                                                                                                        | 90           | 90                    | 5                     | 2.0                 | 46.0                 | 34.0                                                                                                                               | 45.0             | 4.0             | 2500                |
| 90D2                                                                                                                                                                                                        | 90           | 200                   | 40                    | 4.5                 | 44.0                 | 33.3                                                                                                                               | 18.5             | 18.0            | 2700                |
| 90D3                                                                                                                                                                                                        | 90           | 650                   | 81                    | 13                  | 59.1                 | 45.0                                                                                                                               | 6.8              | 12.0            | 2000                |
| 90D4                                                                                                                                                                                                        | 90           | 3800                  | 416                   | 50                  | 61.0                 | 45.1                                                                                                                               | 1.4              | 6.5             | 2000                |
| Step Motors                                                                                                                                                                                                 |              |                       |                       |                     |                      |                                                                                                                                    |                  |                 |                     |
| Motor Number                                                                                                                                                                                                | Voltage (DC) | Stall Torque (in.-oz) | Cont. Torque (in.-oz) | Max. Allow. Amp/Ph. | Min. Req'd Volts/Ph. | KE (Volts /Krp)                                                                                                                    | Resistance (Ohm) | Inductance (Mh) | No Load Speed (rpm) |
| 17S1                                                                                                                                                                                                        | 12-60        | 44.4                  | •                     | 1.2                 | 4.0                  | NA                                                                                                                                 | 3.3              | .3              | •                   |
| 23S1                                                                                                                                                                                                        | 12-60        | 53                    | •                     | 1                   | 5.0                  | NA                                                                                                                                 | 5.1              | 10              | •                   |
| 23S1-02*                                                                                                                                                                                                    | 160          | 60                    | •                     | 1.0                 | 5.0                  | NA                                                                                                                                 | 5.0              | 8               | •                   |
| 23S2                                                                                                                                                                                                        | 12-60        | 53                    | •                     | 3.8                 | 1.2                  | NA                                                                                                                                 | .33              | .6              | •                   |
| 23S3                                                                                                                                                                                                        | 12-60        | 100                   | •                     | 4.7                 | 1.6                  | NA                                                                                                                                 | .35              | .8              | •                   |
| 23S3-06*                                                                                                                                                                                                    | 160          | 150                   | •                     | 2.9                 | 3.4                  | NA                                                                                                                                 | 1.2              | 2.9             | •                   |
| 23S4                                                                                                                                                                                                        | 12-60        | 150                   | •                     | 4.6                 | 2.2                  | NA                                                                                                                                 | .4               | 1.1             | •                   |
| 34S1                                                                                                                                                                                                        | 12-60        | 450                   | •                     | 4.8                 | 3.3                  | NA                                                                                                                                 | .65              | 4.2             | •                   |
| 34S3-11*                                                                                                                                                                                                    | 160          | 450                   | •                     | 5.5                 | 2.9                  | NA                                                                                                                                 | .52              | 2.2             | •                   |
| 42S2-12*                                                                                                                                                                                                    | 160          | 1100                  | •                     | 6.1                 | 3.6                  | NA                                                                                                                                 | .6               | 3.6             | •                   |
| Note: Step Motor performance for speed and torque is based on the type of control used. See motor curves on pages 13-14. *These motors come equipped with a six foot length of cable and are encoder ready. |              |                       |                       |                     |                      |                                                                                                                                    |                  |                 |                     |
| Brushless Servo Motors                                                                                                                                                                                      |              |                       |                       |                     |                      | Note:<br>Brushless Servo Motor Specifications are based in conjunction with the use of the JBU100 Control as found on pages 63-64. |                  |                 |                     |
| Motor Number                                                                                                                                                                                                | Voltage (AC) | Peak Torque (in./oz.) | Cont. Torque (in.-oz) | Peak Current (Amps) | No Load Speed (RPM)  |                                                                                                                                    |                  |                 |                     |
| BU50                                                                                                                                                                                                        | 110/220      | 68                    | 23                    | 2.9                 | 4500                 |                                                                                                                                    |                  |                 |                     |
| BU100                                                                                                                                                                                                       | 110/220      | 135                   | 45                    | 7.1                 | 4500                 |                                                                                                                                    |                  |                 |                     |
| BU200                                                                                                                                                                                                       | 110/220      | 270                   | 90                    | 8.4                 | 4500                 |                                                                                                                                    |                  |                 |                     |



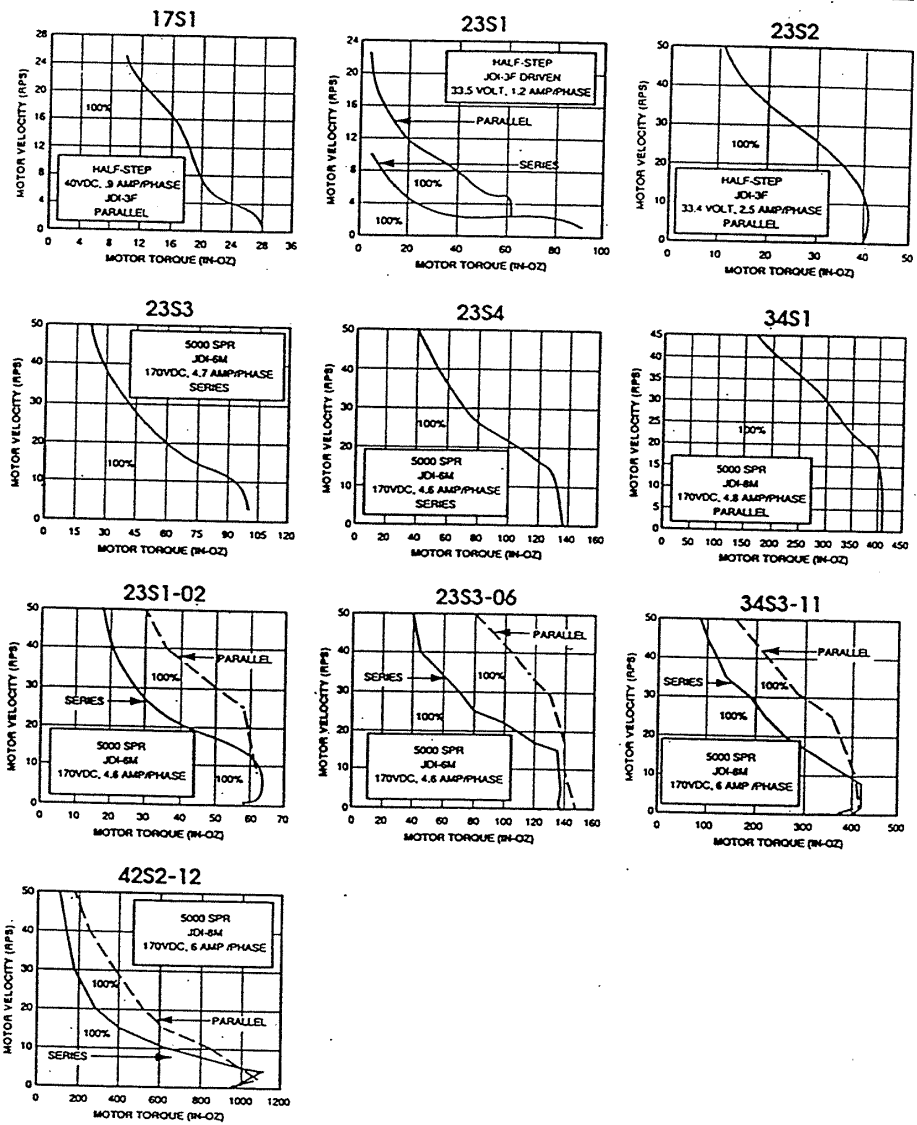
## Motor Dimensions



Note: represents the side of motor mounted to actuator.



## DC Step Motor Torque vs. Speed Curves



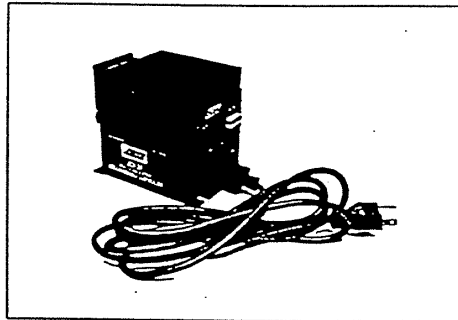
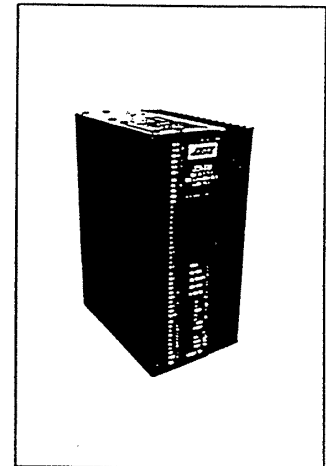
Note: Percentages under curve represent motor duty cycle (assuming proper drive and cooling systems are used).



## "JDI" Series Step Motor Controls

---

- Includes a powerful built-in indexer, driver, and power supply
- Optically coupled step and direction inputs for reliable operation
- Easy to learn English-like instructions
- Built-in editor allows creation of up to 88 different motion programs
- RS-232 communications allows daisy chaining of multiple devices
- Home, extend & retract limits, and multiple programmable inputs and outputs
- Encoder feedback capabilities (JDI-6M & 8M only)
- Short circuit and over temperature protected



### General

The "JDI" series step motor controls are fully compatible with all Jasta-Dynact actuator series, utilizing the step motor as the driving motor. These units are of the highest quality and finest workmanship and are designed to deliver optimum performance to all Jasta-Dynact actuators.



## "JDI" Series Specifications

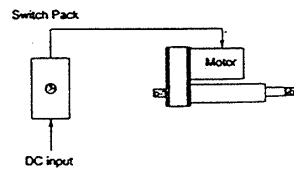
| Common Specifications              |  | JDI-3F                                                                | JDI-6M & JDI-8M                                                                                                                             |
|------------------------------------|--|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Drive Type.....                    |  | 2 phase, bipolar, constant current, MOSFET chopper, 20 KHz fixed..... |                                                                                                                                             |
| Resolutions.....                   |  | 200, 400.                                                             | 200, 400, 1000, 2000, 5000, 10000, 18000, 20000, 21600, 25000, 25400, 25600, 36000, 50000, 50800.....                                       |
| Power (Inputs).....                |  | 115-230V, 50/60Hz, 50VA.                                              | 90-135VAC, 50/60Hz, +5VDC logic.....                                                                                                        |
| Power (Outputs).....               |  | 0.2-2.8 amp/phase programmable.                                       | JDI-6M=0.2 to 6 amps JDI-8M=2 to 8 amps.                                                                                                    |
| Protection (Short circuit).....    |  | Phase to phase, phase to ground.....                                  |                                                                                                                                             |
| Protection (Over Temperature)..... |  | Internal air temperature exceeds 140° F (60° C).....                  |                                                                                                                                             |
| Automatic Current Limit.....       |  | 50% of running current when motor is stationary.....                  |                                                                                                                                             |
| Fault Output.....                  |  | Sinking output to OUTCOM, 5-24VDC, 60mA maximum. Disable LED on.....  |                                                                                                                                             |
| Low Power Mode (Auto reduce).....  |  | Programmable "Hold" current 1% resolution.                            | DIP switch enabled. Current drops to 50% of selected value if no step pulses are received in one second.....                                |
| Environmental (Temperature).....   |  | Drive max. 130° F (55° C), storage -50° F to 185° F (-45° to 85° C).  | Drive heatsink max. 140° F (60° C); Motor case max. 212° F (100° C); Storage -40° F to 185° F (-40° C to 85° C).....                        |
| Environmental (Humidity).....      |  | 0-95% non-condensing.....                                             |                                                                                                                                             |
| Additional Specifications          |  |                                                                       |                                                                                                                                             |
| Operational Acceleration.....      |  | Programmable ramps.                                                   | Optimal non-linear mathematical function or programmable.....                                                                               |
| Step Accuracy.....                 |  | ±0 steps.....                                                         |                                                                                                                                             |
| Position Range.....                |  | ±17 million steps.                                                    | ±2.1 billion steps.....                                                                                                                     |
| Speed Range.....                   |  | 0 to 23,000 pulses/second.                                            | 0 to 750,000 pulses/sec. ±1% max. speed.....                                                                                                |
| Communications                     |  |                                                                       |                                                                                                                                             |
| Type.....                          |  | RS-232 serial or RS-422.                                              | RS-232C serial, 3 wire implementation (Tx, Rx, Ground).....                                                                                 |
| Baud Rates.....                    |  | 300, 1200, 2400, 4800, 9600, 19200.                                   | 1200, 2400, 4800, 9600, 19200.....                                                                                                          |
| Mode.....                          |  | Full duplex.....                                                      |                                                                                                                                             |
| Format.....                        |  | 8 data bits; 1 stop bit; no parity; ASCII characters.....             |                                                                                                                                             |
| Multi-Axis.....                    |  | Daisy chain 32 indexers on RS-422.                                    | Daisy chain up to 36 indexers from a single host RS-232C port.....                                                                          |
| Inputs                             |  |                                                                       |                                                                                                                                             |
| Type.....                          |  | Optically isolated, 5VDC.                                             | Optically isolated, TTL or 5-15VDC                                                                                                          |
| Limits.....                        |  | CW, CCW, HOME.....                                                    |                                                                                                                                             |
| Programmable.....                  |  | Five.                                                                 | Thirteen.....                                                                                                                               |
| Interrupts.....                    |  | One.                                                                  | Inputs 12 & 13. Software selectable.....                                                                                                    |
| Jog, Hold, Stop.....               |  | Three.                                                                | Software assignable to programmable inputs.....                                                                                             |
| Active State.....                  |  | High on Power Up I/O ports TTL logic low.                             | High or low. Software selectable.....                                                                                                       |
| Outputs                            |  |                                                                       |                                                                                                                                             |
| Type.....                          |  | Open collector with pull-up resistors.                                | Optically isolated. Open collector 5-15VDC, 25 milliamp maximum.....                                                                        |
| Fault.....                         |  | N/A.                                                                  | Overtemp, under-voltage or under-current.                                                                                                   |
| Programmable.....                  |  | Two. TTL logic low level-On.                                          | Eight. Active high or low. Software selectable.....                                                                                         |
| Encoder Channels.....              |  |                                                                       |                                                                                                                                             |
|                                    |  | None.                                                                 | Complimentary A & B channel in quadrature with index channel. Maximum input frequency rate of 256 kHz on A & B channel (prequadrature)..... |
| Dimensions                         |  | 4" W x 4" H x 4-1/4" L                                                | JDI-6M = 3" W x 9-1/2" H x 6-7/8" L<br>JDI-8M = 4-9/16" W x 9-1/2" H x 6-7/8" L<br>*Heatsink added                                          |



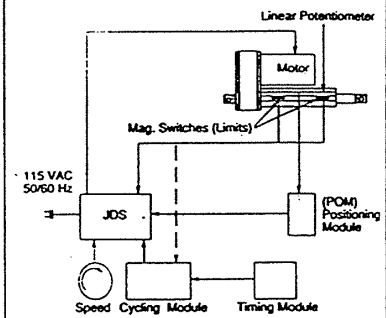


## Control Block Diagrams & Accessories

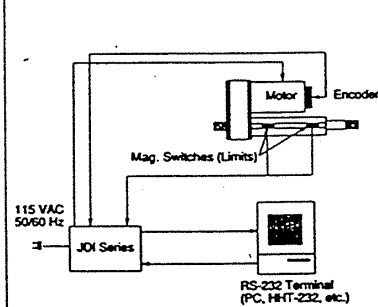
SP01 Switch Pack



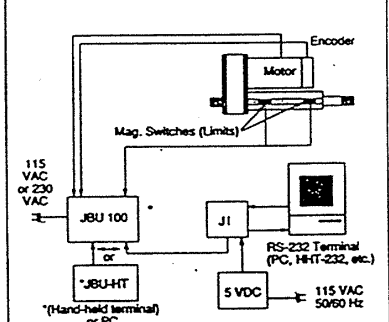
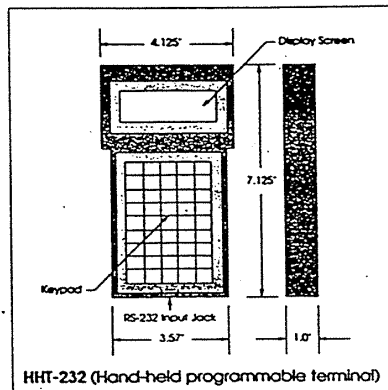
JDS Series



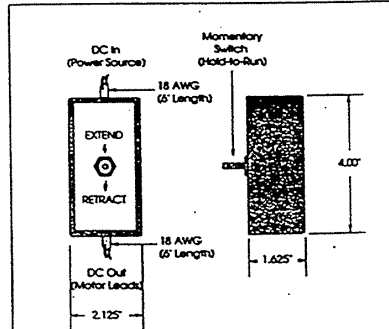
JDI Series



JBU Series



HHT-232 (Hand-held programmable terminal)



SP01 & \*SP01R Switch Pack

\*For driving 90 VDC motors from a 115 VAC input.

## Actuator and Linear Positioner Series Options

### General

Jasta offers the following as options for the actuators and positioners. These items enhance overall performance, protect operating components, and increase longevity.

### Overload Protection

Jasta actuators and positioners should not be continually operated against the end stops, thereby putting the motor in "stall". Overload protection devices such as mechanical limit switches, magnetic reed switches, and linear potentiometers are some of the options which should be incorporated into the actuator or positioner to prevent overload.

### Description:

**BR - Electromechanical Brake:** Required on all units with a ball screw nut combination or an acme lead of .5 inch or over in applications where load is acting opposite to drive force, tending to "back-drive" the system when stopped.

**ES - Environmentally Sealed:** A special sealing on the actuator or positioner to guard against very tough environmental conditions; i.e., snow, heavy rain, washdowns, sandstorm, etc.

**MSR - Magnetic Switch Relay:** The MSR is an add on package which converts the magnetic reed switch signal into a stand alone limit switch package. It can be wired directly in line with the motor and is capable of switching up to 15 amps - enough to handle full motor current on most of Jasta's actuators.

**MS - Magnetic Reed Switches:** Reed switches can be adjusted at any position along the actuator or positioner's switch track. A magnet within the drive nut of the actuator "trips" the switch as it passes. A magnet on the LP carriage "trips" the switch as it passes. Rated: 0.15 amp maximum at 100 VDC. Rated life: 5 million cycles. Refer to page 55 for more information regarding dimensions.

**ZN - Antibacklash Acme Nut:** Removes backlash from the plastic drive nut and is used in precise positioning applications where lost motion cannot be tolerated. Please refer to page 5 for more info.

**LZ - Low Backlash Ballnut:** The ballnut is individually fitted to the screw, giving maximum backlash of 0.002" or less.

**GSR - Guide Rail Supports:** Used only for the Linear Positioner series LP100 and LP150. These support rails serve in accommodating higher loads (See page 48).

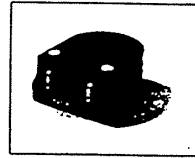
**EN - Optical Encoder:** An encoder is fitted to the actuator or positioner for servo or step motor closed-loop systems. Refer to page 55 for more information regarding dimensions.

**LPO - Linear Potentiometer:** Position of the actuator stroke can be determined by resistance output proportional to the actuator stroke position. The LPO is linear to  $\pm 1\%$  of total stroke. LPO output is 1500 ohms per inch of stroke length. Stroke availability of 2, 3, 6, 9, and 12.

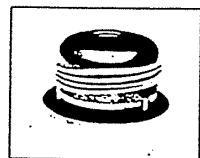
\*LPO is not available with Jasta's "Linear Positioners".

**CN - Encoder or Brake Canister:** A protective canister which houses an encoder or brake option and conveniently includes quick connect/disconnect terminals for all wiring associated with the encoder or brake option. Refer to page 55 for more information regarding dimensions.

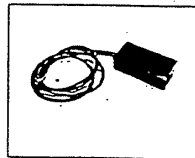
**CND - Encoder and Brake Canister:** Same function as the "CN" option but designed to house both the encoder and brake options. Refer to page 55 for more information regarding dimensions.



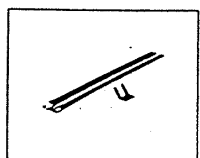
Optical Encoder



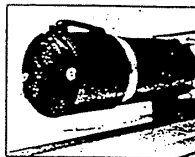
Electromechanical Brake



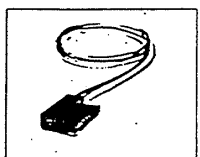
Magnetic Switch Relay



Linear Potentiometer



Brake or Encoder Canister

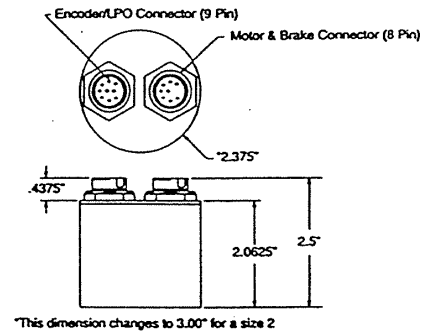


Magnetic Reed Switch

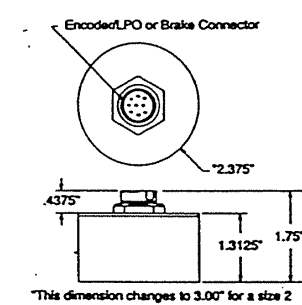


## Actuator and Linear Positioner Option Dimensions

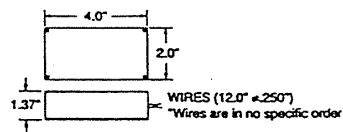
Motor, Brake and Encoder Canister Dimensions (CND)



Motor, Brake or Encoder Canister Dimensions (CN)



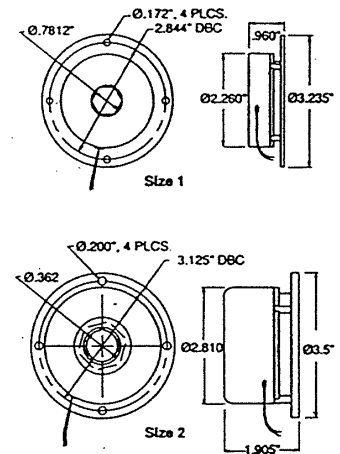
Magnetic Switch Relay (MSR)



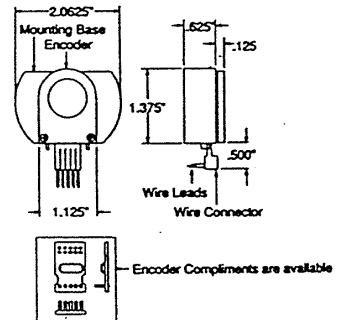
Note: For more information regarding option specifications contact Jasta.



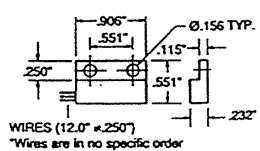
Electromechanical Fail-safe Brake (BR)



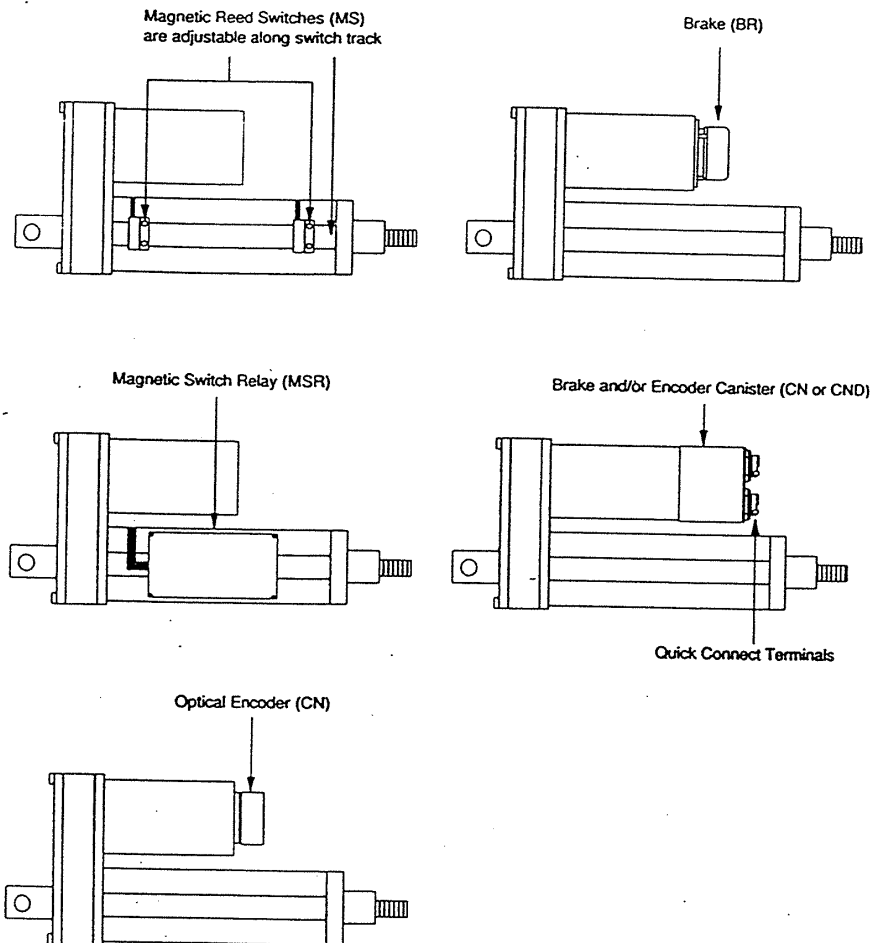
Optical Encoder (EN)



Magnetic Reed Switch (MS)



## Option Locations



All of the option mounting locations as shown in these configurations for the linear actuator are the same for the linear positioner series.





## E2 Series Quick Assembly Optical Encoder

Technical Data, Rev. 1.28, Feb. 1995

The E2 optical incremental shaft encoder is a noncontacting rotary to digital position feedback device designed to easily mount to an existing shaft.

The internal monolithic electronic module converts the realtime shaft angle, speed and direction into TTL-compatible outputs. Simplicity and low cost make the E2 ideal for both high and low volume motion control applications.

The E2 consists of four parts: base, cover, code wheel and encoder module. The encoder module incorporates a lensed LED light source and monolithic photodetector array with signal shaping electronics to produce the two channel bounceless TTL outputs.

The hub diameter is specified when ordering to adapt to any shaft diameter up to 3/8". Standard diameters are stocked. Quick turn around time is also offered for any special order diameter.

The cover is available in three configurations: The standard is a solid flush back which can accommodate a shaft length up to .57". Option 'H' specifies a .375" diameter hole in the flush back for the shaft to pass through. This hole diameter is .500" when the 3/8" diameter hub is specified. Option 'E' provides a cylindrical extension making room for a 3/4" shaft length.

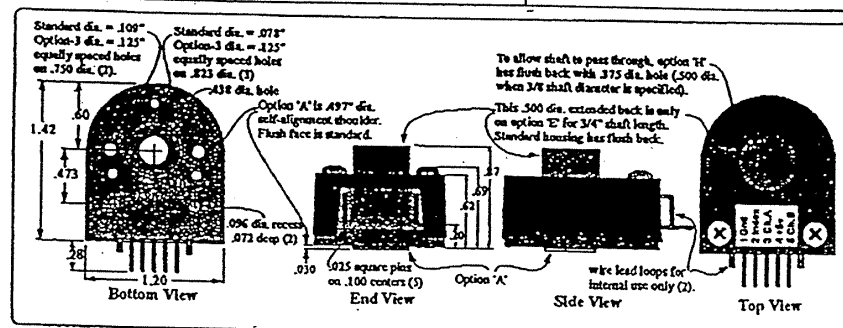
The base provides mounting holes for 2 (2-56 or 4-40) screws in a .750" bolt circle or 3 (0-80) screws in a .823" bolt circle. Option-3 makes all five of these hole diameters .125". If desired, the two .096" diameter recesses will mate with matching aligning pins. The .438" diameter center hole can also mate with a motor boss. The standard base is flat. Option 'A' adds a .497" diameter alignment shoulder designed to slip into a .500" diameter recess centered around the shaft.

### Features

- Quick and simple assembly & dis-assembly
- Rugged screw-together housing
- Low cost
- Accepts  $\pm .010$ " axial shaft play
- Small size
- Tracks from 0 to 100,000 cycles/sec
- 96 to 1024 cycles/rev.
- 384 to 4096 codes per revolution
- 2 channel quadrature TTL squarewave outputs
- Optional index (3rd channel)
- -40 to +100°C operating temperature
- Compatible with HP HEDS-5500
- Fits shaft diameters to 2mm to 3/8"
- Single +5v supply
- Flush back, through shaft hole, or extended back
- Flat or self-aligning base
- Also adapts to 1.812" bolt circle (2 or 3 holes)

### Electrical Specifications:

See our HEDS Optical Encoder Module data sheet.



### Mechanical Specifications

| Parameter                    | Dimension            | Units                |
|------------------------------|----------------------|----------------------|
| Moment of Inertia            | $8.0 \times 10^{-4}$ | oz-in-s <sup>2</sup> |
| Hub Set Screw Size           | 3-48                 | inches               |
| Hex Wrench Size              | .050                 | inches               |
| Encoder Base Plate Thickness | .135                 | inches               |
| 3 Mounting Screw Size        | 0-80                 | inches               |
| 2 Mounting Screw Size        | 2-56 or 4-40         | inches               |

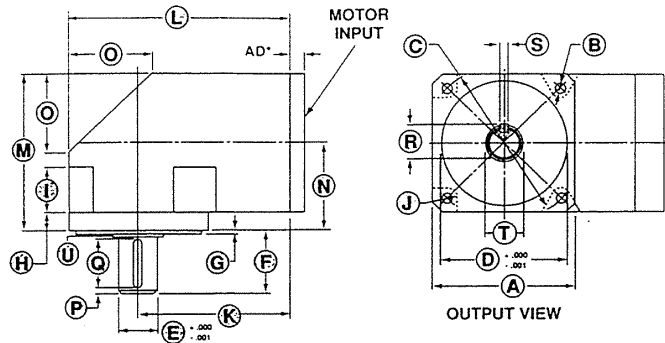
### Mechanical Specifications

| Parameter                    | Dimension       | Units  |
|------------------------------|-----------------|--------|
| 3 Screw Bolt Circle Diameter | .823 $\pm$ .005 | inches |
| 2 Screw Bolt Circle Diameter | .750 $\pm$ .005 | inches |
| Required Shaft Length        | .445 to .570*   | inches |
| with 'E' Option              | .445 to .800*   | inches |
| with 'H' Option              | >.445*          | inches |

\* Add .125" to the required shaft length when using the P-option or R-option adapter plates.

Phone (360) 696-2468 Sales (800) 736-0194 Fax (360) 696-2469  
For Product Information call our automated Fax Service at (360) 696-3836 from your fax machine.  
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## DIMENSIONS



|           | (A)                   | (B)               | (C)                 | (D)                    | (E)                           | (F)                         | (G)                     | (H)                      | (I)                   | (J)            |
|-----------|-----------------------|-------------------|---------------------|------------------------|-------------------------------|-----------------------------|-------------------------|--------------------------|-----------------------|----------------|
| Model No. | Square Flange in (mm) | Bolt Hole in (mm) | Bolt Circle in (mm) | Pilot Diameter in (mm) | Output Shaft Diameter in (mm) | Output Shaft Length in (mm) | Pilot Thickness in (mm) | Flange Thickness in (mm) | Recess Length in (mm) | Radius in (mm) |
| RA 60     | 2.36 (60)             | .197 (5.0)        | 2.756 (70)          | 1.969 (50)             | 0.630 (16)                    | 0.98 (25)                   | .098 (2.5)              | 0.51 (13)                | 1.06 (27)             | R.187 (5)      |
| RA 90     | 3.54 (90)             | .256 (6.5)        | 3.937 (100)         | 3.150 (80)             | 0.787 (20)                    | 1.57 (40)                   | .118 (3.0)              | 0.47 (12)                | 1.25 (32)             | R.263 (7)      |
| RA 115    | 4.53 (115)            | .335 (8.5)        | 5.118 (130)         | 4.331 (110)            | 0.945 (24)                    | 1.97 (50)                   | .138 (3.5)              | 0.55 (14)                | 1.55 (39)             | R.296 (8)      |
| RA 142    | 5.59 (142)            | .433 (11.0)       | 6.496 (165)         | 5.118 (130)            | 1.575 (40)                    | 3.15 (80)                   | .138 (3.5)              | 0.79 (20)                | 3.00 (76)             | R.410 (10)     |
| RA 180    | 7.17 (182)            | .512 (13.0)       | 8.465 (215)         | 6.299 (160)            | 1.969 (50)                    | 3.74 (95)                   | .394 (10.0)             | 0.98 (25)                | 3.12 (79)             | R.500 (13)     |
| RA 220    | 8.66 (220)            | .669 (17.0)       | 9.843 (250)         | 7.087 (180)            | 2.953 (75)                    | 6.10 (155)                  | .591 (15.0)             | 1.38 (35)                | 3.50 (89)             | R.625 (16)     |
| RA300     | 11.81 (300)           | .827 (21.0)       | 13.780 (350)        | 9.843 (250)            | 3.937 (100)                   | 7.09 (180)                  | .787 (20.0)             | 1.97 (50)                | 4.33 (110)            | R.787 (20)     |

|           | (K)                                | (L)            | (M)           | (N)                               | (O)                 | (P)                          | (Q)                   | (R)                   | (S)                      | (T)                     | (U)                       |
|-----------|------------------------------------|----------------|---------------|-----------------------------------|---------------------|------------------------------|-----------------------|-----------------------|--------------------------|-------------------------|---------------------------|
| Model No. | Dist. to Output Centerline in (mm) | Length in (mm) | Width in (mm) | Dist. to Input Centerline in (mm) | Taper Dist. in (mm) | Dist. From Shaft End in (mm) | Keyway Length in (mm) | Keyway Height in (mm) | Keyway Thickness in (mm) | Shoulder Height in (mm) | Shoulder Diameter in (mm) |
| RA 60     | 2.83 (72)                          | 4.02 (102)     | 2.37 (60)     | 1.69 (43)                         | 1.50 (38)           | 118 (3)                      | 0.630 (16)            | 0.71 (18.0)           | 0.197 (5)                | 0.4 (1)                 | 0.87 (22)                 |
| RA 90     | 3.58 (91)                          | 5.35 (136)     | 3.54 (90)     | 2.17 (55)                         | 2.03 (52)           | 197 (5)                      | 1.102 (28)            | 0.89 (22.5)           | 0.236 (6)                | 0.4 (1)                 | 1.42 (36)                 |
| RA 115    | 4.61 (117)                         | 6.85 (174)     | 5.08 (129)    | 2.83 (72)                         | 2.83 (72)           | 276 (7)                      | 1.260 (32)            | 1.06 (27.0)           | 0.315 (8)                | 0.6 (1.5)               | 1.57 (40)                 |
| RA 142    | 6.57 (167)                         | 9.47 (241)     | 6.38 (162)    | 3.58 (91)                         | 3.31 (84)           | 315 (8)                      | 2.480 (63)            | 1.69 (43.0)           | 0.472 (12)               | 0.6 (1.5)               | 1.97 (50)                 |
| RA 180    | 8.39 (213)                         | 11.97 (304)    | 8.15 (207)    | 4.57 (116)                        | 4.49 (114)          | 236 (6)                      | 2.756 (70)            | 2.11 (53.5)           | 0.551 (14)               | 0.8 (2)                 | 2.56 (65)                 |
| RA 220    | 10.12 (257)                        | 14.45 (367)    | 9.92 (252)    | 5.59 (142)                        | 4.82 (123)          | 315 (8)                      | 3.937 (100)           | 3.15 (80.0)           | 0.787 (20)               | 0.8 (2)                 | 3.54 (90)                 |
| RA 300    | 12.60 (320)                        | 18.50 (470)    | 13.78 (350)   | 7.87 (200)                        | 5.91 (150)          | 591 (15)                     | 4.331 (110)           | 4.331 (110.0)         | 1.102 (28)               | 1.2 (3)                 | 4.92 (125)                |

\*AD = Adapter Length. Adapter will vary, depending on motor. Consult appropriate motor sizing chart for details.

## BAYSIDE RIGHT ANGLE PLANETARY GEARHEADS PERFORMANCE SPECIFICATIONS

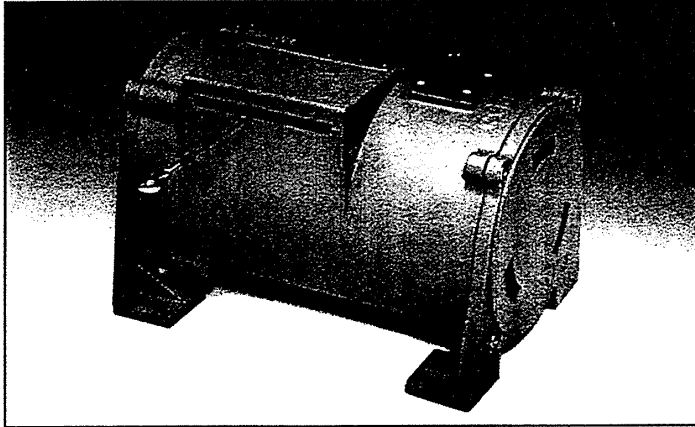
| Model No. | Rated Output Torque in-lbs (Nm) | Peak Output Torque in-lbs (Nm) | Maximum Input Speed (RPM) | Standard Backlash (minutes) | Low Backlash (minutes) | Efficiency (%) |
|-----------|---------------------------------|--------------------------------|---------------------------|-----------------------------|------------------------|----------------|
| RA 60     | 300 (33.9)                      | 498 (56.3)                     | 5000                      | 10                          | 5                      | 90%            |
| RA 90     | 800 (90.4)                      | 1328 (150.1)                   | 5000                      | 10                          | 5                      | 90%            |
| RA 115    | 1600 (180.8)                    | 2656 (300.1)                   | 5000                      | 10                          | 5                      | 90%            |
| RA 142    | 4600 (519.8)                    | 7636 (862.9)                   | 4000                      | 10                          | 5                      | 90%            |
| RA 180    | 8000 (904.0)                    | 15000 (1695.0)                 | 4000                      | 10                          | 5                      | 90%            |
| RA 220    | 12000 (1356.0)                  | 20000 (2260.0)                 | 4000                      | 10                          | 5                      | 90%            |
| RA 300    | 24000 (2711.9)                  | 36000 (4067.8)                 | 2500                      | 10                          | 5                      | 90%            |

| Model No. | Moment of Inertia Oz-in-sec <sup>2</sup> (kg m <sup>2</sup> ) | Torsional Stiffness in-lbs/min (Nm/min) | Maximum Weight lbs (kg) | Radial Load <sup>(1)</sup> lbs (N) | Axial Load lbs (N) |
|-----------|---------------------------------------------------------------|-----------------------------------------|-------------------------|------------------------------------|--------------------|
| RA 60     | 6x10 <sup>-4</sup> (4x10 <sup>-6</sup> )                      | 50 (5.7)                                | 5 (2.3)                 | 400 (1779.4)                       | 400 (1779.4)       |
| RA 90     | 3x10 <sup>-3</sup> (2x10 <sup>-5</sup> )                      | 80 (9.0)                                | 9 (4.1)                 | 600 (2669.0)                       | 600 (2669.0)       |
| RA 115    | 7x10 <sup>-3</sup> (5x10 <sup>-5</sup> )                      | 140 (15.8)                              | 20 (9.1)                | 1100 (4893.2)                      | 1100 (4893.2)      |
| RA 142    | 5x10 <sup>-2</sup> (4x10 <sup>-4</sup> )                      | 360 (40.7)                              | 43 (19.5)               | 1800 (8007.1)                      | 1800 (8007.1)      |
| RA 180    | 9x10 <sup>-2</sup> (6x10 <sup>-4</sup> )                      | 640 (72.3)                              | 85 (38.6)               | 2800 (12455.5)                     | 2800 (12455.5)     |
| RA 220    | 3x10 <sup>-1</sup> (2x10 <sup>-3</sup> )                      | 960 (108.5)                             | 160 (72.6)              | 10000 (44484.0)                    | 10000 (44484.0)    |
| RA 300    | 1x10 <sup>-1</sup> (7x10 <sup>-2</sup> )                      | 1200 (135.6)                            | 340 (154.5)             | 12000 (53380.8)                    | 12000 (53380.8)    |

(1) Radial loads are at 1.00 inches (25.4 mm) from the face of the gearhead.

# Cable-Extension Position Transducer

- Medium to Long Range / Industrial Grade
- Incremental-Encoder Output



## Standard Specifications:

### GENERAL

Range ..... 0-75, -100, -150, -200, -250, -300, -400, -450, -500, -550 inches  
 Extended Ranges to 1750 inches ..... please consult factory  
 Weight ..... 7 lb. typical  
 Housing Material ..... Powder-Painted Aluminum  
 Optional ..... Stainless Steel  
 Sensor ..... Incremental Optical Encoder  
 Electrical Connector ..... MS3102E-14S-6P  
 Mating Connector (included) ..... MS3106E-14S-6S

### ELECTRICAL

Input Voltage ..... 4.5 - 13.2 VDC  
 Options ..... see fig. 4  
 Input Current ..... 50 mA max.  
 Output Stage ..... see fig. 4, option 1  
 Output Channels ..... A, B (see fig. 1)  
 Optional Channels ..... Index and compliments of A, B, & Index

### PERFORMANCE

Accuracy ..... 0.04% of Full Stroke +/- 1 pulse  
 Repeatability ..... 0.02% of Full Stroke  
 Resolution:  
     English ..... 100 pulses per inch nominal\*\*  
     Metric ..... 5 pulses per mm nominal\*\*

### MECHANICAL

Cable Tension ..... see fig. 3  
 Cable Diameter ..... 0.024 in. \*\*  
 Cable Fitting ..... MS20668 Stainless Steel Eye Fitting

### ENVIRONMENTAL

Operating Temperature ..... 0° to 160°F  
 Environmental Suitability ..... Indoor/Outdoor  
 Operating-Humidity, Splash ..... NEMA 4, IP 67  
 Vibration ..... up to 10 G's to 2000 Hz

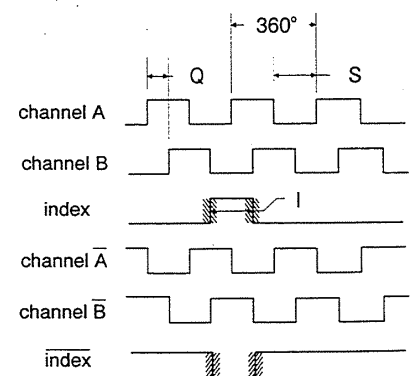
\*\*See order code for more options

# PT9150

The PT9150 is for long range measurement applications that require a digital incremental encoder position feedback signal. Available in extended ranges up to 1750", the PT9150 comes in a variety of resolutions and output stages that will fit almost any requirement.

Like other members of Celesco's innovative family of NEMA 4 rated cable-extension transducers, the PT9150 can be installed in minutes, function properly without perfect parallel alignment, and fit into areas unsuitable for rod-type measurement devices. When its stainless-steel cable is retracted, the PT9150 is only 6" long. Its small-size-and-low-cost-to-measurement ratio offers remarkable flexibility and value.

fig. 1 Output Waveforms



Q: quadrature 90° +/- 30°    S: symmetry 180° +/- 10°  
 I: index 90° to 270°

**celesco**

Celesco Transducer Products, Inc. 7800 Deering Avenue Canoga Park, CA 91309 Tel: (800) 423-5483 Fax: (818) 340-1175

fig 2 Cable Exit

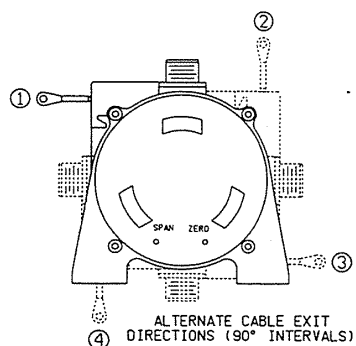


fig 3 Cable Tension

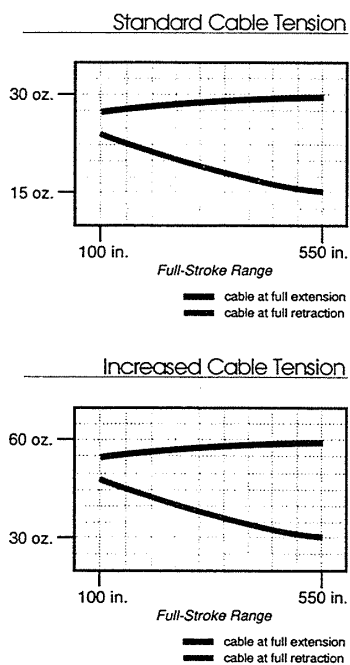
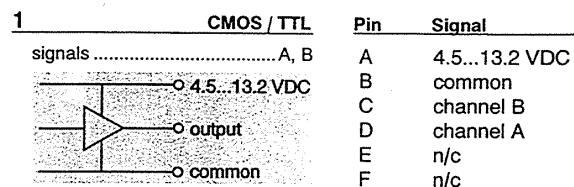
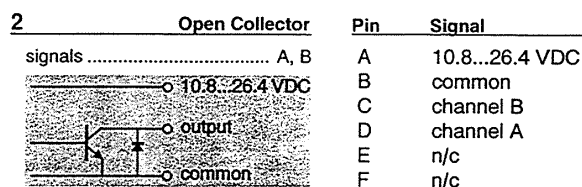
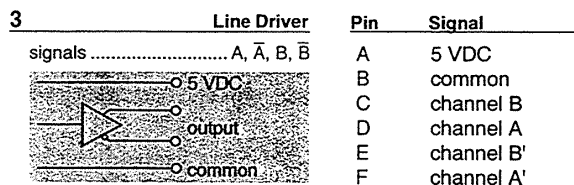
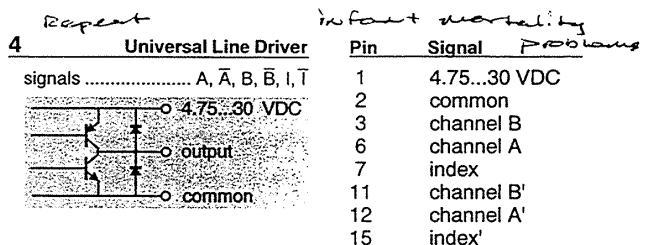
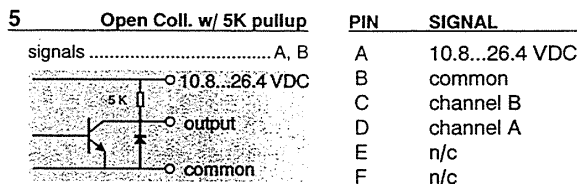


fig 4 Output Stage

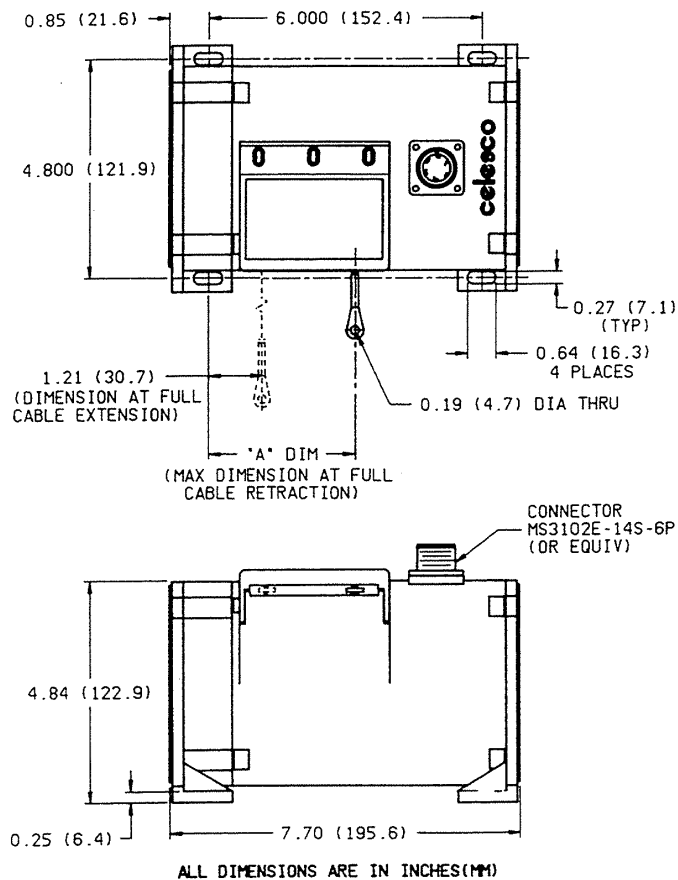


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**fig. 5 Outline Drawing**



| Dimension "A"  |                      |                      |               |                      |                      |
|----------------|----------------------|----------------------|---------------|----------------------|----------------------|
| English        |                      |                      | Metric        |                      |                      |
| Range<br>(in.) | 0.024"<br>dia. cable | 0.047"<br>dia. cable | Range<br>(mm) | 0.61mm<br>dia. cable | 1.19mm<br>dia. cable |
| 75             | 1.36"                | 1.50"                | 2500          | 34.5mm               | 38.2mm               |
| 100            | 1.40"                | 1.60"                | 3750          | 35.7mm               | 40.7mm               |
| 150            | 1.50"                | 1.80"                | 5000          | 38.2mm               | 45.6mm               |
| 200            | 1.60"                | 1.99"                | 6250          | 40.6mm               | 50.5mm               |
| 250            | 1.70"                | 2.19"                | 7500          | 43.2mm               | 55.6mm               |
| 300            | 1.80"                | 2.38"                | 8750          | 45.7mm               | 60.5mm               |
| 350            | 1.90"                | 2.58"                | 10000         | 48.2mm               | 65.5mm               |
| 400            | 2.00"                | n/a                  | 11250         | 50.8mm               | n/a                  |
| 450            | 2.10"                | n/a                  | 12500         | 53.3mm               | n/a                  |
| 500            | 2.20"                | n/a                  | 13750         | 55.9mm               | n/a                  |
| 550            | 2.30"                | n/a                  | 15000         | 58.4mm               | n/a                  |

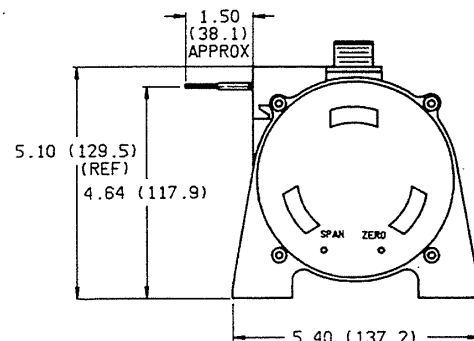
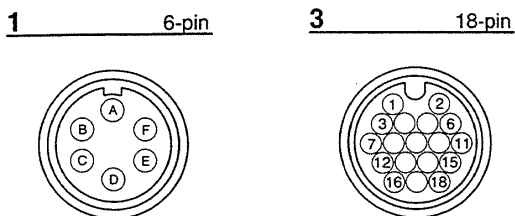


**fig. 6 Mating Connectors**



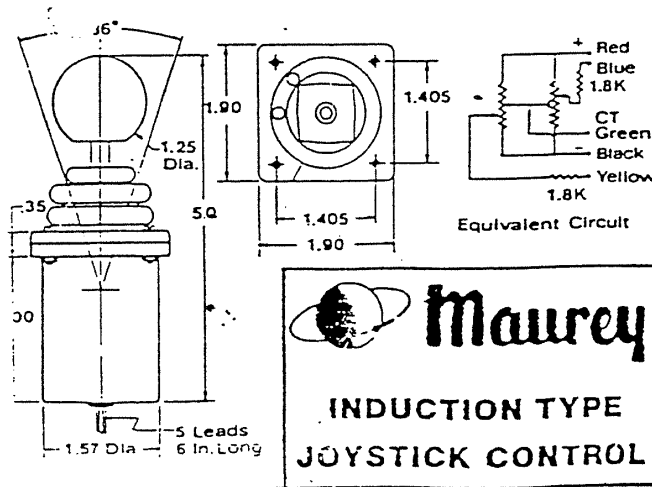
DURING INSTALLATION  
REFERENCE WIRING INFO.  
SUPPLIED WITH TRANSDUCER

**celesco**

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PT9150.PM5 7.18.94

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|                                   |                                       |
|-----------------------------------|---------------------------------------|
| Operating Voltage:                | 4.5 to 15.0 Volts, D.C.               |
| Current:                          | 15 ma at 10 Volts, D.C.               |
| Output Impedance:                 | 1800 $\Omega$ (Signals)               |
| Center Tap Impedance:             | 340 $\Omega$                          |
| Equivalent Noise Resistance:      | NONE                                  |
| Temperature Range:                | -30° to 105° C                        |
| Center Tap Voltage:               | 50% of Input Voltage                  |
| Resolution:                       | Infinite                              |
|                                   | 20,000,000 cycles                     |
| Leads                             | 6 inch standard length<br>color coded |
| Knob has spring return to center. |                                       |
| Voltage Swing:                    | $\pm 10\%$ of Operating Voltage       |

## Chapter 1: Introduction

### General

The 7500 series computer chassis from Industrial Computer Source provide the ruggedness and durability required for industrial applications. There are several models, i.e. mounting configurations, of chassis available in this series, all with essentially the same construction but slightly different features.

| <u>MODEL</u> | <u>MOUNT</u>         | <u>BACKPLANE</u>  |
|--------------|----------------------|-------------------|
| 7515-33H     | RACK                 | PASSIVE, 15 SLOT  |
| 7508-33H     | RACK                 | MOTHERBOARD MOUNT |
| 7615-33H     | BENCH TOP            | PASSIVE, 15 SLOT  |
| 7608-33H     | BENCH TOP            | MOTHERBOARD MOUNT |
| 7915-33H     | FLOOR                | PASSIVE, 15 SLOT  |
| 7918-33H     | FLOOR                | MOTHERBOARD MOUNT |
| 7815-33H     | RACK, KEYBD DRAWER   | PASSIVE, 15 SLOT  |
| 7818-33H     | RACK, KEYBD DRAWER   | MOTHERBOARD MOUNT |
| 7500-XC      | RACK, EXPANSION      | PASSIVE, 15 SLOT  |
| 7600-XC      | BENCH TOP, EXPANSION | PASSIVE, 15 SLOT  |

The passive backplane chassis are designed and built for the most demanding of industrial needs. These units have a 15 slot, all AT, passive backplane which accepts your selection from a wide range of available CPU cards. These CPUs plug into the backplane as any other adapter card would. The backplane itself has very few components. The components it does have are the necessary sockets to accept up to fifteen adapter cards and LED indicating circuitry, Industrial Computer Source's Bus Power Check™ circuitry, for each power supply output,  $\pm 5\text{VDC}$  and  $\pm 12\text{VDC}$ .

The difference between the chassis is the mounting configurations, i.e. whether they rack mount in 19" equipment cabinets, set on a bench top, or set on the floor with or without optional shock mount stands. The motherboard mounting chassis appear identical to the passive backplane units from the outside. Inside they have provisions for mounting typical XT or AT compatible motherboards rather than a passive backplane. These chassis offer you the capability to take your choice of motherboards from "office" systems and ruggedize them for use in factory floor environments. The hole pattern for acceptable mother boards, such as full size and "Baby AT" boards, is found in the installation section of this manual.

### Power Supply

The power supply in this series of chassis provides more than adequate power for even the most rigorous requirements. A switching type power supply is incorporated to provide large amounts of power without the heat and weight associated with transformer, linear power supplies. The total output of the supply is 315 Watts with up to 35 Amps available from the +5VDC supply and up to 10 Amps at +12VDC.

## Disk Drives

The chassis, except for the expansion chassis, will accept up to three half-height disk drive devices or a full-height and a half-height. The mounting configuration for drives utilizes shock mounts to permit use in high vibration and shock applications. The expansion chassis, the 7500 and 7600, can accept fixed disk drives in a drive cage but provide no front panel access.

## Cooling and Filtration

The chassis are designed for use in industrial areas. Positive pressurization of the chassis is accomplished through the use of heavy duty fans. Two 106 CFM fans are included in the card cage area with an additional 24CFM fan mounted in the power supply module. These three fans, with their filtered intakes, provide protection for the full system, including the disk drives, from environmental dirt and grit.

## Specifications

### Power Supply:

35 Amps @ +5 VDC  
1 Amp @ -5 VDC  
10 Amps @ +12 VDC  
1 Amp @ -12 VDC

### Fuse:

5 Amp, 250V, 3AG, Fast Blow

### Power Requirements:

120VAC +10%/-25% or 220VAC +10%/-25% , 49-61Hz  
The power supply switches automatically  
The supply will operate normally at 400Hz input power frequency - however, the system is NOT UL/CSA  
Recognized in that mode of operation.

### Operating Temperature:

+5 to +50°C, 5 - 95% R. H. Non-condensing

### Storage Temperature:

-5 to +75°C, 5 - 95% R. H. Non-condensing

### Shock Tolerance:

5g, Half sine, 15mSeconds duration

### FCC Classification:

Meets FCC Part 15, Class A Emission Limits

### UL Ratings:

UL 478, UL Recognized

**Construction:**

Chassis: 0.055" Aluminum Alloy, Gold Zinc finish

Front Panel: 0.125" Aluminum Alloy, Medium Texture Sherwin Williams Paint #F63-A-3080

**Fans, Filtration:**

Card Cage Area: 2, 106 CFM, 4.68" Fans, filtered to 45 ppi

Power Supply Module: 1, 24 CFM, 3.15" Fan, filtered to 45 ppi

**Connectors, External:**

Keyboard 5 pin DIN connector, front and rear  
Accessory power outlet plug, rear

**Switches:**

Power on, CPU reset, front panel  
(Keylock power on/reset switch optional)

**Shock Capacity:**

Three half-height on shock mounts or one half-height and one full-height on shock mounts. 3.5" devices will require an adapter mounting bracket for 5.25" device mounts.

**Weight:**

35 Lbs (16.0 Kg)  
(Shipping - 45 Lbs (20.5 Kg))

**Dimensions:**

Rack Mount: 23"(58.42cm) D x 7.0"(17.78cm) H x 19"(48.26cm) W, Front Panel, 17"(43.18cm) W chassis

Bench Top: 23"(58.42cm) D x 7.0"(17.78cm) H x 17"(43.18cm) W

Floor Mount: 25"(63.50cm) D x 17"(43.18cm) H x 7.0"(17.78cm) W

**Backplane:**

15 slot, 4 layer, low capacitance backplane standard configuration, all AT (16 bit) slots. Rear panel has 15 slot access. Different configurations available on special request.

**Motherboard:**

Mother Board CPU, 8 slot rear panel with DIN keyboard connector cutout. Hole patterns in floor of chassis to accept most standard AT and "Baby AT" mother boards.

|                                                                                   |                                                                       |                                 |
|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------|---------------------------------|
|  | <b>SUBMINIATURE MARK SENSOR</b><br>Components for advanced technology | <b>MQ</b><br><b>Mark Sensor</b> |
|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------|---------------------------------|

Subminiature with built in amplifier, with detection speed of 1,000 times per second achieved.



MQ-VD2AR Mark Sensor  
 (diffused reflection type)  
 Sensing distance: 2 cm approx. 0.8 inches

- High speed detection: 1,000 times/second
- Subminiature with built-in amplifier
- Mark sensing or bar code (UPC code)
- Detection of 0.5 mm 0.02 inch width's possible
- Light ON or OFF output detection is selectable
- Wide range operation 12/24 V DC
- Environmental resistance (IEC IP67)
- Horizontal or vertical mounting
- Simple sensitivity adjustment

## ORDERING INFORMATION

| Detection method    | Product name         | Part No.          | Operating condition         | Setting distance        | Packing q'ty. |              |
|---------------------|----------------------|-------------------|-----------------------------|-------------------------|---------------|--------------|
|                     |                      |                   |                             |                         | Inner carton  | Outer carton |
| Diffused reflection | MQ-VD2AR Mark Sensor | MQ-VD2AR-DC12-24V | Light ON, Dark ON selection | 2 cm approx. 0.8 inches | 1             | 10           |

Note: A special mounting bracket is provided as accessory.

## RATINGS AND PERFORMANCE SUMMARY

### 1. Ratings

| Item           | Description                                                   |
|----------------|---------------------------------------------------------------|
| Operating side | Rated operating voltage<br>DC 12/24 V                         |
|                | Rated current consumption<br>Less than 35 mA (excluding load) |
| Load side      | Output current capacity<br>100 mA max.                        |

### 2. Performance summary

| Item                            | Type                       | Diffuse reflective                                                               |
|---------------------------------|----------------------------|----------------------------------------------------------------------------------|
|                                 |                            | MQ-VD2AR                                                                         |
| Light source                    |                            | Red light emitting diode*                                                        |
| Standard target                 |                            | 2.0 mm .079 inch mark on white field                                             |
| Minimum mark detection width    |                            | 0.5 mm .020 inch (at rated setting distance)                                     |
| Operating voltage range         |                            | 9.6 to 30 V DC including ripple (P-P)                                            |
| Max. sensing distance           |                            | 2±0.2 cm                                                                         |
| Hysteresis                      |                            | Less than 20 % (at rated setting distance)                                       |
| Detection speed                 |                            | 1,000 times/second (at 2 mm .079 inch black and 1 mm .039 inch white mark width) |
| Insulation resistance (Initial) |                            | Between I/O terminal and outer case 20 MΩ (with 500 V DC megger)                 |
| Dielectric strength (Initial)   |                            | Between I/O terminal and outer case 500 V AC for 1 minute                        |
| Vibration endurance             |                            | 10 to 55 Hz (1 min cycle) amplitude 1.5 mm .059 inch 2 h on 3 axes               |
| Malfunction vibration           |                            |                                                                                  |
| Shock endurance                 |                            | 100 G 6 times in each direction                                                  |
| Malfunction shock               |                            |                                                                                  |
| Protective construction         |                            | Diecast case immersion proof form (Equivalent to IEC IP67)                       |
| Usable ambient conditions       | Usable ambient light       | Incandescent lamp: less than 3,000 lux; Sunlight: less than 10,000 lux.          |
|                                 | Detection object           | Translucent, opaque body and mark                                                |
|                                 | Usable ambient temperature | 25°C to +55°C 13°F to +131°F                                                     |
|                                 | Usable ambient humidity    | Less than 85%                                                                    |
| Indicator                       |                            | Indicator lights with light input (red), surplus indicator (red)                 |

Notes: 1. Undesignated measurement conditions are at rated operating voltage, storage battery power source, ambient temperature +20°C -59°F standard detection object, light receiving surface light intensity less than 200 lux.  
 2. Because the rated setting distance and response distance for the diffused reflection type are measured with the standard detection object, the distance will vary depending upon the material, color, and size of the object.